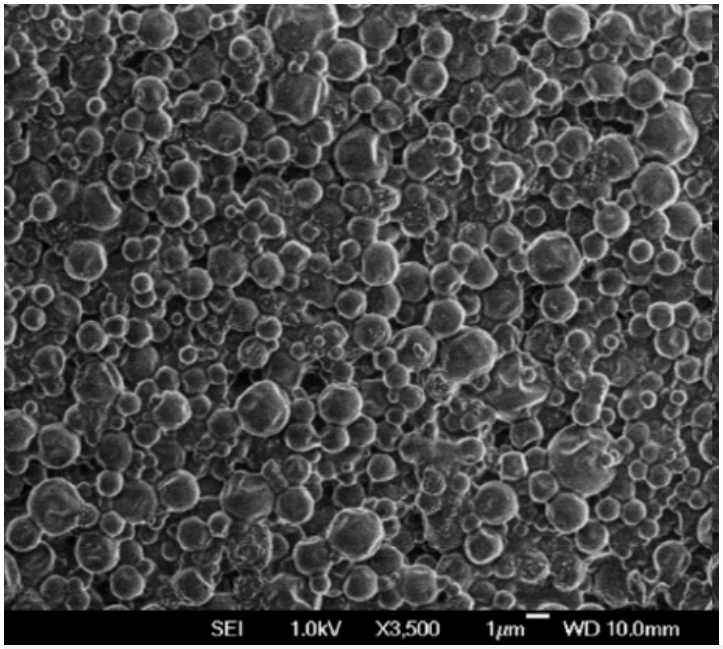
ISSN 2217-379X

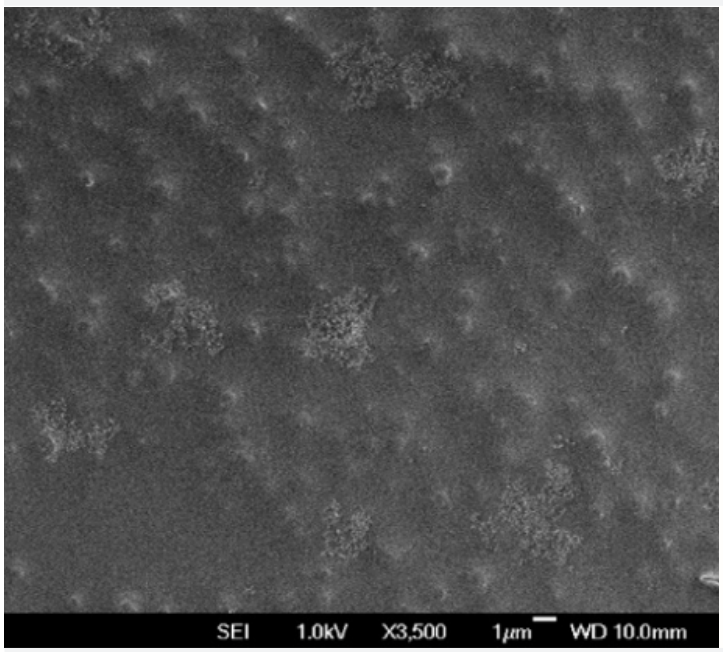
University of Novi Sad
Faculty of Technical Sciences
DEPARTMENT OF GRAPHIC
ENGINEERING AND DESIGN

Volume **14**
Number **4**
December **2023**

JGED

JOURNAL OF GRAPHIC ENGINEERING AND DESIGN





JGED

JOURNAL OF GRAPHIC ENGINEERING AND DESIGN

4/2023

Volume 14, Number 4, December 2023.

Published by

UNIVERSITY OF NOVI SAD, SERBIA
Faculty of Technical Sciences
Department of Graphic Engineering and Design

PUBLISHED BY

University of Novi Sad
Faculty of Technical Sciences
DEPARTMENT OF GRAPHIC ENGINEERING AND DESIGN

Address:
Faculty of Technical Sciences,
Department of Graphic
Engineering and Design,

Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia

Telephone numbers:
+381 21 485 26 20
+381 21 485 26 26
+381 21 485 26 21

Fax number:
+381 21 485 25 45

Email:
jged@uns.ac.rs

Web address:
www.grid.uns.ac.rs/jged

Frequency: 4 issues per year
Printing: Faculty of Technical Sciences, Department of Graphic Engineering and Design

Circulation: 200

Electronic version of journal available on www.grid.uns.ac.rs/jged

E-ISSN 2217-9860

The journal is abstracted/indexed in the Scopus and Directory of Open Access Journals

CIP - Katalogizacija u publikaciji
Biblioteka Matice srpske, Novi Sad
655
JGED : Journal of Graphic Engineering and Design / editor Dragoljub Novaković. - Vol. 1, No. 1 (nov. 2010) - Sciences, Department of Graphic Engineering and Design,
2010-. 30 cm
Dva puta godišnje
ISSN 2217-379X
COBISS.SR-ID 257662727

Art Director
Uroš Nedeljković

Layout design
Bojan Banjanin

Journal cover design
Nada Miketić

JOURNAL OF GRAPHIC ENGINEERING AND DESIGN

Volume 14, Number 4, December 2023.

Contents

Original scientific paper
http://doi.org/10.24867/JGED-2023-4-005

The effectiveness of Canned Coffee packaging's graphic design elements in consumers' decision-making process

ABSTRACT

Studies recently focused on the important roles of graphic design elements in drawing consumers' attention. The present study focuses on finding out the effectiveness of graphic design elements and colors of canned coffee packaging in consumers' decision-making process. This study was performed in two stages. The first stage included making graphic design elements: image, shape, and typography. In the second stage, the values were modified to see which color was the most attractive to the consumer by distributing questionnaires to 135 respondents. The study demonstrates the importance of packaging visuals, implying the need for attractive graphic design elements. Regarding the image, respondents preferred the photograph over the illustration. Meanwhile, regarding shape, respondents preferred fluid rather than pattern, and regarding typography, they preferred display over text. To conclude, respondents preferred light-colored photography, pattern and display. This result could be used as a reference in designing beverage packaging.

KEY WORDS
graphic design elements, image, shape, typography, color

Indriana Anggun Febrianti
Andreas Slamet Widodo
Ahmad Faizin

Sebelas Maret University,
Surakarta, Indonesia

Corresponding author:
Indriana Anggun Febrianti
e-mail:
indrianaanggun37@student.uns.ac.id

First received: 25.9.2022.
Revised: 23.11.2022.
Accepted: 20.12.2022.

Introduction

A marketing department needs to understand consumer logic in the impulsive buying decision of a product in order to improve its sales. Recent studies show that packaging product serves as an opportunity to communicate products to consumers in-store (Rettie & Brewer, 2000; Silayoi & Speece, 2007; Simms & Trott, 2010). Facts show that 70% of purchasing decisions are made in store, even in a planned purchase. (Inman, Winer & Ferraro, 2009). Thus, a product marketing strategy may heavily depend on its packaging, one of the most important elements affecting consumers' decision-making process (Hall, Binney & Barry O'Mahony, 2004).

Consumers interact with the product at the point of purchase (Kauppinen-Räisänen & Luomala, 2010; Madzharov & Block, 2010), and their perception of the product plays an important role before making a final purchasing decision. (Ampuero & Vila, 2006). Hence, failure in marketing the product will likely bring a negative impact to the product, despite its high value (Ahmad & Ahmad, 2015). Packaging is known to play pivotal role at the point of purchase. Thus, it is pivotal to scrutinize how packaging affects one's purchasing decision (Deng & Kahn, 2009) in order to avoid losing the competition (Ahmed, Ahmed & Salman, 2005).

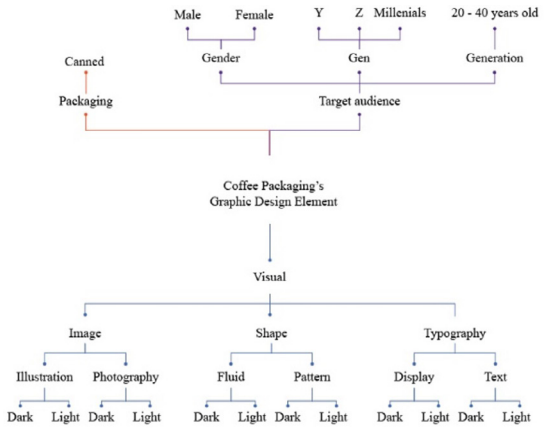
According to Ampuero & Vila (2006), a product image is divided into two elements, graphic and structural elements. The former consists of branding, illustration, typography, color, graphic, and information layout. Meanwhile, the latter comprises materials, form, size, and format. The present study focuses on graphic design elements, including image, shape, typography, and color. Previous studies have explored the importance of graphic design elements and color (Grossman & Wisenbilt, 1999) in creating a hedonic and sensory expectation that may influence the actual product experience (de Sousa, Carvalho & Pereira, 2020) and play important roles in building consumers' perception (Wang, 2013) and affect their decision-making process (Silayoi & Speece, 2007).

High-class consumers' products are often related to a photograph of the product itself, while products for costumers from price-sensitive groups are associated with illustration (Ampuero & Vila, 2006). According to Wu & Xu (2018), packaging does not only display the product specifically but also triggers emotion and creates intuitive visual effects for consumers. Picture implementation should represent the product name, brand, and product illustration and draw consumers' emotional interest. Furthermore, it is recommended to use photography rather than illustration in designing a packaging product. However, the combination of these two elements, or even the absence of both elements, in packaging may also serve as an effective choice in designing packaging (Pensasitorn, 2015).

Typography consists of two types: types of text designed to be read in extended passages and small size and those covering various types of font (Bigelow, Dyson & Lonsdale, 2017). Typography of packaging product for higher-class consumer segments usually use bold, roman typography and use capital letter to give an elegant impression, while the products for lower consumer segments usually use serif and sanserif typography (Ampuero & Vila, 2006). The important difference in typography lies in font and display. According to Childers & Jass (2002), fonts used in product packaging may act as a feature to give casual or luxurious impressions. A font could also affect hedonic perception and behaviors. It does not only function to communicate written information but also as a product of hope and association, which will affect its acceptance (de Sousa, Carvalho & Pereira, 2020).

Packaging color is also discussed from different perspectives in literature. It shapes consumers' first impression in their first purchase, affects their perception and emotion, and improves the packaging's visual aesthetics to attract consumers' attention (Kuo, Chang & Lai, 2021). It also differentiates a product from others (Garber, Burke & Jones, 2000) and help consumers choose the product taste (Piqueras-Fiszman, Velasco & Spence, 2012). Color affects consumers differently, depending on their ages (Marshall, Stuart & Bell, 2006; VanHurley, 2007). High-class consumer segments tend to prefer cool and dark packaging, whereas lower consumer classes are reported to prefer lighter or colorful packaging (Ampuero & Vila, 2006). Packaging visuals act as a pivotal marketing strategy in achieving high sales, which could be attained by considering elements of graphic designs, i.e., image, shape, typography, and color. Grounded from the description above, it is important to scrutinize the factors affecting consumers' perception when deciding to make a purchase and explore the packaging to provide a guideline in developing design and communication strategies.

A mind map was made to develop the canned coffee packaging (Figure 1). The mind map functions to develop the creativity in a problem solving-process prior to its implementation in the visual image (Chen, 2008).



» **Figure 1:** *The mind map of canned coffee packaging graphic design development*

The mind mapping result is then transformed into mood board (figure 2) to turn abstract ideas into concrete ones, which is used as a reference to build the canned coffee packaging design.

» **Figure 2:** *Canned Coffee Packaging Mood Board*

The target audiences were men and women of Y, Z, and Millennial generations between 20-40 years of age (productive age). Therefore, the mood board was intended to build a young, exclusive product images.

Making a canned coffee packaging design conceptually involved two stages: sketch and visual design. The sketch functions to develop a mind map before turning it into visual designs. The first sketch of the first element (image) (see figure 3-A) presents a picture of a glass of coffee with a splash effect and coffee beans falling into the glass. This packaging design aims to present a casual, calm, and mature impression through this photograph. The second sketch (see figure 3-B) presents an illustration aiming to deliver a warm, elegant and classic product impression by displaying coffee bean, coffee flower, and unroasted coffee bean.

» **Figure 3:** *Photograph (A) and Illustration (B) Image Sketches*

The pattern shape sketch (Figure 4-A) presents a repeated abstract shape to deliver a playful and modern impression.

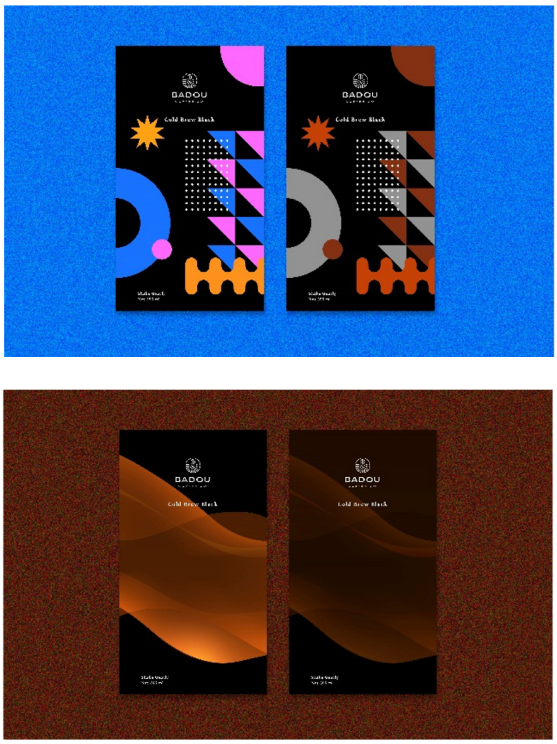
» **Figure 4:** *Pattern (A) and Fluid (B) Shape Sketches*

Meanwhile, the fluid design (figure 4-B) represents an idea obtained from water splash. It provides the product with an elegant, modern, and mature impression. The display typography sketch (figure 5-A) presented a combination of typographies, including coffee beans and water splash with free, irregular styles. This sketch showed youthful, fun, and vintage senses. In contrast, the text typography sketch (figure 5-B) presents a more structured typography showing clean, bold, simple impressions.

» **Figure 5:** *Display (A) and Text (B) Typography Sketches*

The canned coffee packaging design is made following the sketch before being digitally applied. The values of the three graphic design elements (image, shape, and typography) were manipulated in order to create the final visuals of the canned coffee packaging design.

Figure 6: Image Visual Design (Photograph and illustration)



» **Figure 7:** *Shape Visual Design (Pattern and Fluid)*

» **Figure 8:** *Typography Visual Design (Display and Text)*

Problem Statement

Product packaging serves as the main promoter in communicating a brand. Its physical attribute is a means to achieve success through first impressions (Cortina-Mercado, Del Este & Rico, 2017) and an important factor in winning the competition in store racks (Bloch, 1995). Packaging also serves as a communication medium for consumers, as it allows them to gain product knowledge and eventually enhance the brand effects through graphic design elements (Wu & Xu, 2018).

Therefore, the present study aims to determine the most attractive graphic design elements in canned coffee packaging. This study hypothesizes that study respondents prefer a photograph in a can packaging. It is also expected that respondents prefer fluid shapes on can packaging. The third hypothesis in this study was that respondents preferred text typography. Lastly, this study expects that respondents prefer all graphic design elements in canned coffee packaging manipulated with bright color rather than dark color.

Method

Respondents

This study involved 135 respondents (female respondents 60%, male respondents 40%) between 20 and 40 years of age. They were asked to respond to the questionnaire to measure the effectiveness of the packaging design from consumers' taste perspectives.

Samples

Samples in this study were ready-to-drink canned coffee products commonly consumed and found in all supermarket. In order to avoid using certain brand, a fictitious coffee brand was made. The packaging and mockups were made using Adobe Illustrator and Adobe Photoshop CS6. The created design is saved in JPG. An adjustment of RGB color was made to ensure accurate color representation in computer or phone screen.

In the first stage of the study, six packaging samples were compared related to their graphic design elements, consisting of image (Figure 9), shape (Figure 10), and typography (Figure 11). In general, samples were designed using same product size and information with black and brown background to create an equal design.

Regarding the first element, i.e., image, brown appeared as the dominant color on can packaging with photographic visuals, while black with white gradation at the can bottom was dominant in packaging with illustrative visuals. Regarding the shape,

both fluid and pattern shape was colored black as its base color. Whereas the typography, both packaging types used black and brown as the base color.

» **Figure 9:** *Image (Photograph vs Illustration)*

» **Figure 10:** *Shape (Pattern vs Fluid)*

» **Figure 11:** *Typography (Display vs Text)*

In the second stage, twelve packaging samples were used by manipulating the value of the image (Figure 12), shape (Figure 13), and typography (Figure 14).

Respondents were requested to select the values of their preferred graphic design elements following their answers in the first stage.

» **Figure 12:** *Value of image 1) Bright Photograph; 2) Dark Photograph;3) Bright Illustration; 4) Dark Illustration*

» **Figure 13:** *Value of shape 1) Bright pattern; 2) Dark pattern; 3) Bright fluid; 4) Dark fluid*

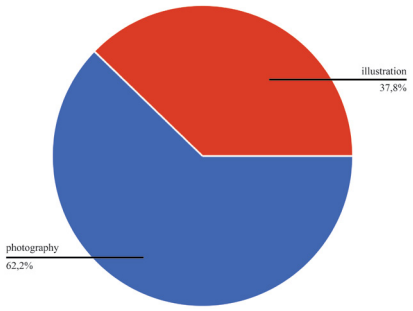
» **Figure 14:** *Value of typography: 1) Bright display; 2) Dark display; 3) Bright text; 4) Dark text*

Results

This study used a general question, " Do you pay attention to the packaging visuals when buying a product?" to determine the importance of graphic design elements of packaging. In this regard, 98.5% of respondents answered "Yes", and 1.5% answered "No." The next question reads, " Do you think the visual display of a packaging important?", and 96.3% of

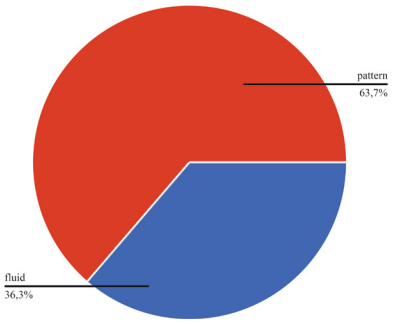
respondents answered “Yes,” while 3.7% of respondents answered “No”. Respondents in this study (n=135) were requested to show, using a scale of 1-5, how important a visual design is for them. 37% of respondents stated that it is highly important, 29.6% stated that it is important, and 33.3% stated fairly important.

In the first stage, respondents were asked to select their favourite canned coffee packaging design. In this regard, most of them (62.2%) preferred photography, while 37.8% preferred illustration (Figure 15).



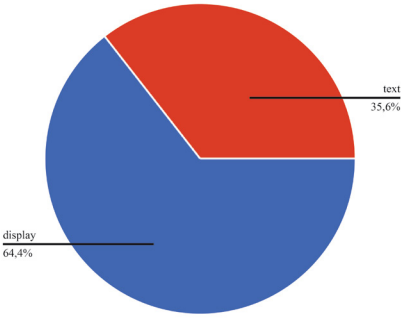
» **Figure 15:** *Respondents’ preference regarding the Image (Photograph vs. illustration).*

Regarding shape, most respondents (63.7%) preferred fluid, while 36.3% preferred pattern (Figure 16).



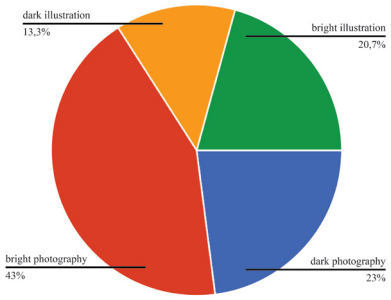
» **Figure 16:** *Respondents’ preference regarding the shape (pattern vs. fluid).*

They also preferred display typography (64.4%) , over text typography (35.6%) (Figure 17).

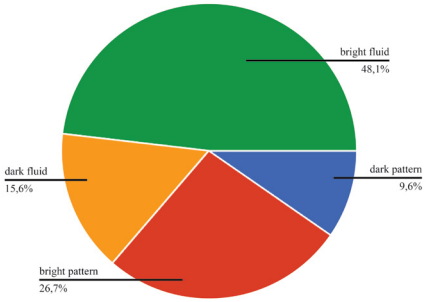


» **Figure 17:** *Respondents’ preference regarding the typography (display vs.text).*

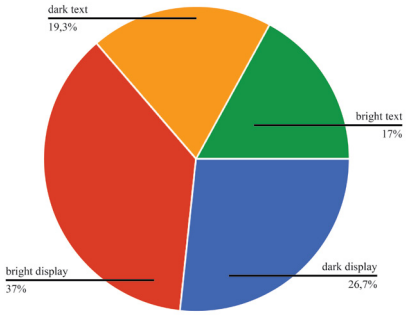
The second stage of the study showed that most respondents prefer brighter graphic design elements. 43% of respondents were found to prefer a bright photograph for the image element (Figure 18), 48.1% of respondents preferred bright fluid shape (Figure 19), and 37% of respondents preferred bright displays for the typography (Figure 20).



» **Figure 18:** *Respondents’ preference of the image value (photograph vs. illustration).*



» **Figure 19:** *Respondents’ preference of shape (pattern vs. fluid).*



» **Figure 20:** *Respondents’ preference of typography (display vs.text).*

Discussion

Based on the study result, visual elements do significantly affect consumers’ decision-making process. According

to Rettie & Brewer (2000), 70% of purchasing decisions are made when seeing the product, implying that graphic design is needed to deliver attractive packaging visuals. Regarding the element of image, photography was viewed as more attractive than illustration. This preference is possibly due to the fact that they have more product description through properly positioned, appetizing photograph. This is supported by Kovac et al. (2019), who state that photograph is more attractive and powerful to appetize consumers' impulsive purchase. In other words, the first hypothesis was accepted.

Regarding the element of shape, respondents prefer fluid shape rather than pattern, supporting the second hypothesis. Fluid shape is preferred as it presents more white spaces when appropriately designed. Furthermore, respondents prefer display typography over text, rejecting the third hypothesis. The use of display emphasizes the font beauty and exhibits larger visuals, thus making it more attractive and readable (Bigelow, Dyson & Lonsdale, 2017).

This study also combines respondents' interest in graphic design elements and the value of all graphic design elements, finding that respondents were more interested in brighter packaging with photograph, fluid, and display elements. Manipulating one or more graphic design elements, including colors, may positively affect consumers' attention and their preference. Packaging color could also communicate product information at the point of sales (Mohebbi, 2014).

Conclusions

This study concludes that a packaging's visual design significantly affects respondents' decision-making process. Hence, graphic design elements are important to create attractive packaging visuals for consumers. Photograph, fluid shape, and display typography could be used to make a packaging's visual design that may affect consumers' decision-making process. It should be noted that brighter colors are preferred over darker colors.

Photography could be applied if the product contains ingredients displayed on the packaging visuals. It is also recommended to apply fluid shapes with colors reflecting the product; for instance, using brown color on the canned coffee packaging represents the product itself. Moreover, the application of display as typography is also recommended while paying attention to its readability to allow consumers to recognize the product easier. These findings were obtained from respondents 20 to 40 years of age, a different finding possibly obtained when involving different age groups and products.

Funding

The research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Ahmad, A. M. K. & Ahmad, Q. M. K. (2015) Factors Influence on Packaging Design in an Impulse Consumer Purchasing Behavior: A Case Study of Doritos Pack. *International Journal of Marketing Studies.* 7 (6), 92. Available from: doi: 10.5539/ijms.v7n6p92

Ahmed, A., Ahmed, N. & Salman, A. (2005) Critical issues in packaged food business. *British Food Journal.* 107 (10), 760–780. Available from: doi: 10.1108/00070700510623531

Ampuero, O. & Vila, N. (2006) Consumer perceptions of product packaging. *Journal of Consumer Marketing.* 23 (2), 102–114. Available from: doi: 10.1108/07363760610655032

Bigelow, C., Dyson, M. & Lonsdale, M. (2017) What exactly is the difference between a text and a display typeface?. *Visible Language.* 51 (1), 134–143.

Bloch, P. H. (1995) Seeking the Ideal Form. *Journal of Marketing*. 59 (3), 16–29. Available from: doi: 10.2307/1252116

Chen, J. (2008) The using of mind map in concept design. In: *The 9th International Conference on Computer-Aided Industrial Design and Conceptual Design: Multicultural Creation and Design, CAID & CD '2008, 22-25 November 2008, Kunming, China.* Piscataway, IEEE. pp. 1034–1037. Available from: doi: 10.1109/CAIDCD.2008.4730739

Childers, T. L. & Jass, J. (2002) All dressed up with something to say: Effects of typeface semantic associations on brand perceptions and consumer memory. *Journal of Consumer Psychology.* 12 (2), 93–106. Available from: doi: 10.1207/153276602760078631

Cortina-Mercado, M., Del Este, U. & Rico, P. (2017) Effect of Packaging Design in the Purchase Decision Process: a Comparison of Generations. *Global Journal of Business Research.* 11 (2), 11–26.

de Sousa, M. M. M., Carvalho, F. M. & Pereira, R. G. F. A. (2020) Do typefaces of packaging labels influence consumers' perception of specialty coffee? A preliminary study. *Journal of Sensory Studies.* 35 (5). Available from: doi: 10.1111/joss.12599

Deng, X. & Kahn, B. E. (2009) Is your product on the right side? The "location effect" on perceived product heaviness and package evaluation. *Journal of Marketing Research.* 46 (6), 725–738. Available from: doi: 10.1509/jmkr.46.6.725

Garber, L. L., Burke, R. R. & Jones, J. M. (2000) *The role of packaging color on consumer purchase consideration and choice.* Marketing Science Institute. Report number: 00-104.

Grossman, R. & Wisenbilt, J. (1999) What we know about consumers' color choices. *Journal of Marketing Practice: Applied Marketing Science.* 5 (3), 78-88. Available from: doi: 10.1108/EUM0000000004565

Hall, J., Binney, W. & Barry O'Mahony, G. (2004) Age Related Motivational Segmentation of Wine Consumption in a Hospitality Setting. *International Journal of Wine Marketing.* 16 (3), 29–43. Available from: doi: 10.1108/eb008777

Inman, J. J., Winer, R. S. & Ferraro, R. (2009) The interplay among category characteristics, customer characteristics, and customer activities on in-store decision making. *Journal of Marketing*. 73 (5), 19–29. Available from: doi: 10.1509/jmkg.73.5.19

Kauppinen-Räisänen, H. & Luomala, H. T. (2010) Exploring consumers' product-specific colour meanings. *Qualitative Market Research*. 13 (3), 287–308. Available from: doi: 10.1108/13522751011053644

Kovac, A., Kovacevic, D., Bota, J. & Brozovic, M. (2019) Consumers' preferences for visual elements on chocolate packaging. *Journal of Graphic Engineering and Design.* 10 (1), 13–18. Available from: doi: 10.24867/JGED-2019-1-013

Kuo, L., Chang, T. & Lai, C. C. (2021) Visual color research of packaging design using sensory factors. *Color Research and Application.* 46 (5), 1106–1118. Available from: doi: 10.1002/col.22624

Madzharov, A. V. & Block, L. G. (2010) Effects of product unit image on consumption of snack foods. *Journal of Consumer Psychology.* 20 (4), 398–409. Available from: doi: 10.1016/j.jcps.2010.06.007

Marshall, D., Stuart, M. & Bell, R. (2006) Examining the relationship between product package colour and product selection in preschoolers. *Food Quality and Preference.* 17 (7–8), 615–621. Available from: doi: 10.1016/j.foodqual.2006.05.007

Mohebbi, B. (2014) The art of packaging: An investigation into the role of color in packaging, marketing, and branding. *International Journal of Organizational Leadership.* 3 (2), 92–102. Available from: doi: 10.33844/ijol.2014.60248

Pensasitorn, W. (2015) The Use of Images in Graphic Design on Packaging of Food and Beverages. *Journal of Economics, Business and Management.* 3 (12). Available from: doi: 10.7763/joebm.2015.v3.351

Piqueras-Fiszman, B., Velasco, C. & Spence, C. (2012) Exploring implicit and explicit crossmodal colour-flavour correspondences in product packaging. *Food Quality and Preference.* 25 (2), 148–155. Available from: doi: 10.1016/j.foodqual.2012.02.010

Rettie, R. & Brewer, C. (2000a) The verbal and visual components of package design. *Journal of Product & Brand Management.* 9 (1), 56–70. Available from: doi: 10.1108/10610420010316339

Silayoi, P. & Speece, M. (2007) The importance of packaging attributes: A conjoint analysis approach. *European Journal of Marketing*. 41 (11–12), 1495–1517. Available from: doi: 10.1108/03090560710821279

Simms, C. & Trott, P. (2010) Packaging development: A conceptual framework for identifying new product opportunities. *Marketing Theory.* 10 (4), 397–415. Available from: doi: 10.1177/1470593110382826

VanHurley, V. L. (2007) *The influence of packaging color on consumer purchase intent: the influence of color at the point of purchase.* PhD thesis, Michigan State University. Available from: doi: 10.25335/M5RB6WF82

Wang, E. S. T. (2013) The influence of visual packaging design on perceived food product quality, value, and brand preference. *International Journal of Retail and Distribution Management*. 41 (10), 805–816. Available from: doi: 10.1108/IJRDM-12-2012-0113

Wu, Y. & Xu, C. (2018) Cognition and design: Selection of illustration style in native products packaging design based on neurocognitive science. *NeuroQuantology.* 16 (6), 385–390. Available from: doi: 10.14704/nq.2018.16.6.1594

http://doi.org/10.24867/JGED-2023-4-013

Re-evaluation of the Cerebral Palsy's orthotic need in Adaptive Seating Orthosis (ASO) design

ABSTRACT

Adaptive seating orthosis (ASO) for Cerebral Palsy (CP) patients in Malaysia mostly are imported, highly expensive for the bottom millions, bulky and complicated design structure, and not accommodating users' preferences. Through a study involving 10 CP patients with their parents/guardians in Malaysia, the goal of this paper is to re-assess the design needs of CP's orthotic in ASO design. The purpose of the study is to identify the difficulties, as well as the ergonomic and functional problems, in caring for CP patients with the current ASO. The result of the study revealed several of the problems that parents/guardians face while taking care of the CP patient, mainly caused by technical flaws in the current ASO design. Therefore, a few design criteria have been proposed to solve the addressed problems. The contribution of this study will help as a preference for the improvement and development of ASO design.

KEY WORDS

Cerebral Palsy, Adaptive Seating Orthosis, design thinking, ergonomics, product design

Muhammad Jameel Mohamed Kamil [1,2]
Mohd Najib Abdullah Sani [1, 3]

[1] Universiti Malaysia Sarawak, Design Technology Programme, Faculty of Applied and Creative Arts (FACA), Sarawak, Malaysia
[2] Universiti Malaysia Sarawak, Institute of Creative Arts and Technology (iCreate), Sarawak, Malaysia
[3] Universiti Malaysia Sarawak, University Industry Centre (UnIC), Sarawak, Malaysia

Corresponding author:
Muhammad Jameel Mohamed Kamil
e-mail: mkmjameel@unimas.my

First received: 28.6.2022.
Revised: 16.12.2022.
Accepted: 4.1.2023.

Introduction

One of the Six Strategies Trusts outlined in the Eleventh Malaysia Plan (RMK-11) is to enhance the well-being of Malaysian people by providing better healthcare, particularly in the B40 group. The treatment for CP in Malaysia; a long-term condition that developed when areas of the brain that control muscles are damaged is one of the main health and well-being problems. Postural control deficiencies as a major component of gait disturbances in CP patients have been proposed by medical experts. The lack of suitable seating modifications has made it difficult to reach an independent sitting and has had an impact on their quality of life. Due to the condition, various Adaptive Seating Orthotics (ASO) products have been purposely developed and produced for CP patients. However, the majority of ASOs for CP patients in Malaysia are imported, very costly for the bottom million, heavy with bulky and complicated design structure that does not fit Malaysian anthropometric details, daily used and preferences (Hui et al., 2011; Kamaralzaman et al., 2018; Tan & Yadav, 2008; Tharshini et al., 2016). As a response, it is essential to have a good ASO design that can easily accommodate day-to-day activities, purposely created based on Malaysian anthropometrics, and affordable. Matos et al. (2014) claim that the last decade has seen an increased emphasis on the design of medical equipment for the disabled, especially on patient safety, and a few projects have been set up to strengthen these elements. In any event, Matos et al. (2014) also claimed that most multidisciplinary organisations responsible for the advancement of products for disabled have struggled to recognise and integrate good design as a fundamental feature. In addition, the perception was compounded by the belief that the vast majority of items designed for disabled do not adequately address the actual and realistic needs of users. For instance, issues such as symbolic functions, aesthetic or, in outrageous cases, ergonomic and functionality are not generally considered significant as mechanical performance or economic

and innovative variables. Therefore, it is important that the product development of ASO for CP patients should include the reflection of designers in considering influential variables such as users' actual needs, accessibility, ergonomic elements, and aesthetics. Thus, our research aims to re-evaluate the ergonomic issues, needs, functional and practical problem for the development of CP's ASO design in Malaysia, based on the aforementioned claims. The research model of the study was based on the framework of Ergonomics Ergo-system. Following that, based on the data analysis, a few design criteria will be outlined in order to determine the most suitable and appropriate design preferences for the improvement and development of ASO design.

Cerebral Palsy (CP)

According to Colver, Fairhurst & Phaorah (2014), CP was defined by the International Executive Committee for the Definition of CP as a category of persistent mobility and posture growth disorder, triggering cognitive activity limitations caused by non-progressive diseases that have emerged in the developing fetus or infant brain. In other words, CP is a neurological disorder that is caused by a non-progressive brain injury, malformation, or damage to the brain that happens during the growth of the child's brain (before birth, during or shortly after birth). Meanwhile, according to Hughes et al. (2012), CP was described as a collection of persistent disorders of movement and posture development that cause activity restriction and are attributable to non-progressive problems in the developing fetus or new-born brain.

According to Tharshini et al. (2016), most of the babies born with CP problems are prone to complications such as; (1) motor movement problems, (2) stiff or loose muscle problems, (3) weak muscle problems and (4) body balances problems. Sahinoglu, Coskun & Bek (2017) suggest that the typical musculoskeletal problems seen among CP patients are decreased flexor of the hip and knee. The thoracic-lumbar vertebrae are flexed to counteract the posterior inclination of the pelvis. Back-shifting balance compensation triggers thoracic kyphosis. However, in the thoracolumbar region, there is more flexion that complicates the regulation of the head, and the patient attempts to keep the head in place by slanting it forward or backward, which creates swallowing and speech difficulties. The deterioration of motor behaviour is closely related to a loss of postural control, creating a never-ending cycle and deteriorating the patient's static and dynamic stabilisation. Posture coordination defects have been indicated by medical professionals as a major component of gait disorders in CP patients due to a musculoskeletal problem, as a result, they find it difficult to remain motionless and spend the majority of their time sitting.

Adaptive Seating Orthosis (ASO)

Physical and occupational therapists regularly recommended ASO for CP patients since the 1960s to enhance their function and strengthen their developmental capacities. According to Bolas & Boyle (2017) through overcoming participation barriers in daily life activities such as play, ASO improves the occupational performance of CP patients. In specific, ASO is widely prescribed to strengthen posture in persons with disabilities, while improving volitional upper limb control. This is in line with previous studies by various researchers who have been actively searching for the most suitable choice of ASO for CP patients (Angsupaisal et al., 2017; Chung et al., 2008; Polhan et al., 2019; Ries, Novacheck & Schwartz, 2014; Ryan, 2016; Sahinoglu, Coskun & Bek, 2017; Vekerdy, 2007). The seating orthosis developed by Polhan et al. (2019) and Sahinoglu et al. (2017) are shown in Figure 1 and Figure 2.

» **Figure 1:** *Definitive custom seating orthosis wheelchair, adapted from Polhan et al. (2019)*

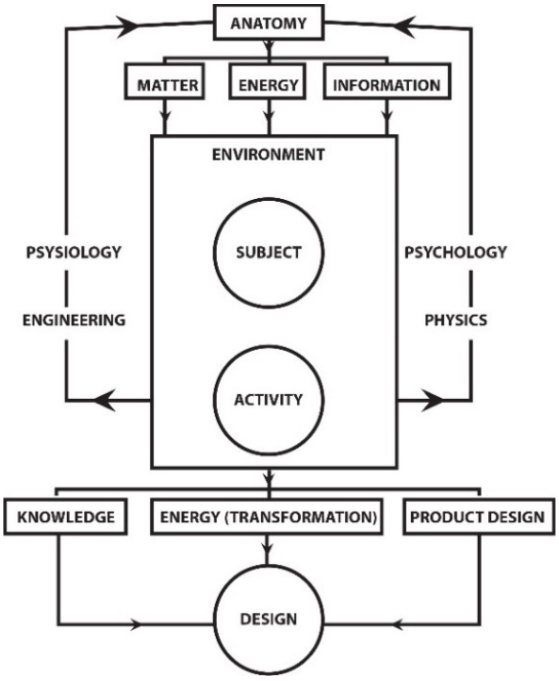
» **Figure 2:** *Adjustable seating orthosis, adapted from Sahinoglu, Coskun & Bek (2017)*

Based on an interview with parents regarding the seating and engagement of CP patients, Bolas and Boyle (2017) found that using the autonomous mobility and level of social skills of ASO patients is considered meaningful if they can be sociable, learn new skills, be self-sufficient, have fun, and achieve personal objectives. Therefore, Bolas and Boyle indicated that when evaluating the best for CP patients and their families, it is important to figure out what is relevant and important outcomes.

Based on the study conducted by Rigby, Ryan & Campbell (2009), the majority of parents reported favourable outcomes from using the ASO, such as their kid sitting better, did more, and was more active during the intervention phase by using the ASO for longer periods. Several parents reported improving the abilities of their child, while others claimed that their children were happier and more eager to sit and perform activities, and that they were now able to engage in face-to-face social contacts, leading to more socialising with family and friends. After the devices were withdrawn at the conclusion of the intervention procedure, some parents reported that their children were more passive and less engaged, while others reported that their children were less sociable and engaging. Nevertheless, parents considered the seating devices comfortable and easy to use during the intervention process, and many indicated that their child needed less assistance from the caregiver. Almost a quarter of parents mentioned how their child could join the family for meals, sports and social interactions now. Parents also reflected favourably on the portability of the ASO, stating that they used it while paying visits to relatives and acquaintances at their homes, they took the ASO with them, and they used it effectively in restaurants. A few families confirmed, however that the ASO did not fulfil the needs of every family. The most popular concerns were that the ASO does not give enough assistance, or the essential stability required by their child. These parents indicated that by using the ASO, they watched their child more closely. Several parents said that their child was bothered by the activity seat's straps and preferred to be confined rather than limited.

The Ergonomics Ergo-System Framework

Bridger's (2008) ergonomics ergo-system framework was used to develop the design needs assessment model. In this research, the framework is developed as a design paradigm to help designers' design thought throughout the stages as follows: (1) analysing the case empathically; (2) brainstorming and developing an idea for the user's requirements (based on the results of the analysis stage); (3) conceptualize and modelling process; (4) and reviewing the design prototype on a regular basis (see Figure 3). Generally, the framework serves as a blueprint for optimising system operation, but it can also be used in product design. The following five groups of theoretical elements of ergonomics speed up the process: (1) Psychology; (2) Engineering; (3) Anatomy; (4) Physics; and (5) Physiology. The system's foundation includes the subject's synchronisation in a specific setting. In order to make sense of the interaction, the subject's state or condition (matter) in a given environment or space must be understood. In theory, the state or situation will illuminate information on the subject's reflection on the physics of the world being experienced, as well as how it affects the subject's psychology and the need for it. The articulation of anatomy and physiological requirements, on the other hand, would provide much needed design information for further refinement. The design assessment model is used in this study to determine the design needs of CP patients and their parents/guardians for product design development.



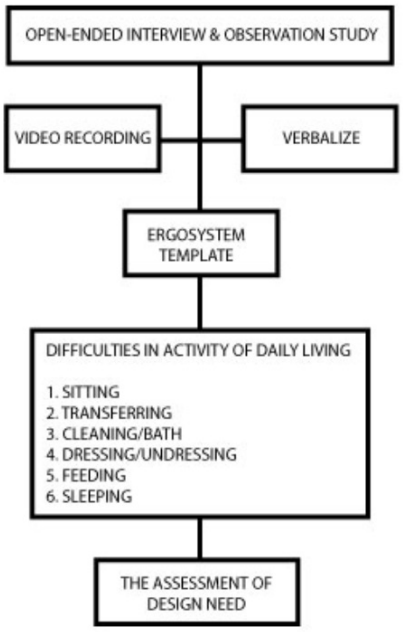
» **Figure 3:** *Ergonomic Ergo-system Framework, adapted from Bridger (2008)*

The framework of design needs assessment

As illustrated in Figure 4, the framework of design needs assessment (Sani et al., 2019; Kamil, Shi & Sani, 2020) was developed by incorporating ergonomic contexts, as described in Bridger's (2008) ergonomics ergo-system framework. The framework, in general, serves as a qualitative research blueprint for the procedures and strategy to assessing design needs. The framework's basis comprises an assessment of the subject's situation through an open-ended interview and observation study in a specific environment, such as the activity of daily living. The theoretical aspects incorporated from Bridger's (2008) ergonomics ergo-system framework will be utilised as a reference throughout the procedure. Video and verbalised explanations were gathered as empirical data, which was then analysed to determine the design needs.

Methodology

Based on Cross's (2001) proposal on the forms of design research, the nature of this study will be the 'research for design'; aims to create an artefacts, design methods, and



» **Figure 4:** *The Framework of Design Needs Assessment, adapted from Sani et al. (2019); Kamil, Shi & Sani (2020)*

forms of modelling. In this research, the objectives as follow: 1) to determine the technical difficulties faced by the guardians in taking care of the CP patient; and (2) to analyse the ergonomic issues due to the technical aspect in the existing ASO support. These research objectives were derived based on the context of the study; the context that helps to exemplify the primary subject, limits, and perimeter of information to be investigated, which is hoped to establish the design preferences for the development of ASO for Malaysian CP patients. Based on the incorporated ergonomic contexts by Sani et al. (2019) and Kamil, Shi & Sani (2020) the framework of design needs assessment divides the procedures and illustrates the strategy in accomplishing the research objective. In this study, the assessment of the CP's orthotic need for the development of ASO design was identified based on the investigation of problems faced by the guardians and CP patients such as the ergonomics and functional issues in using the existing ASO. The study was focused on the six activities of daily living, as follow: (1) sitting; (2) dressing/undressing; (3) transferring; (4) cleaning/giving bath; (5) feeding; and (6) sleeping. Nevertheless, this study also investigates the burden of cost and maintenance in using the existing ASO. Open-ended interview and observation study were conducted with 10 parents/guardian of the Malaysian CP patients. The study was conducted at Hospital Universiti Sains Malaysia in Kelantan during the first year of the research activity. The interview and observation were recorded using Zoom Q2 HD Video Recorder, and the video was processed using AVS Video Editor Software. The theoretical framework of the observation will be focus on behaviour analysis of the Malaysian CP patients (Austin & Delaney, 1998; Zainal Abidin, Christoforidou & Liem, 2009; Kamil, Zainal Abidin & Hassan, 2018; Kamil, Zainal Abidin & Hassan, 2019b; Kamil, Shi & Sani, 2020; Kamil & Sani, 2021; Kamil, Hua & Sani, 2022). To extract the clear explanation and build the abstract thinking of the parent or the guardian, the analysis of interview in recorded video was systematically coded into information categories (Glaser & Strauss, 2017; Kamil, Zainal Abidin & Hassan, 2019a).

The analysis of the interview in recorded video was part of the process to gain an empathetic understanding and inform a clear design need. Using three phases of coding: (1) open coding; (2) axial coding; and (3) selective coding, the written verbal transcriptions from the interview data were analysed and methodically classified into information categories (Creswell, 2009; Saldaña, 2009). For example, in a study of issues in sitting activity (see Table 1), the researcher categorised the parents/guardian's utterance's selected emphases and obtained the utterance's attributes. Open coding starts with the generation of simple descriptive labels or speech analysis features in this work. In the 'Open Codes' column, an extract of open code from one of those utterance analyses may be seen. Axial codes, which are more abstract conceptual categories, are created from the open codes. Selective coding, in particular, required sorting and relabelling comparable coded data into conceptual groupings that were reduced from open codes. During the cycle, the code is fine-tuned to get the best match, and more than one axial code may be generated. In addition, data that was "divided" or "fractured" during the open coding process will be carefully reconstructed. At this level, the axis is a category developed from open coding. One of the aims of early coding is to identify these dimensions and organise the available codes along them.

The open codes in Table 1 have, for example, been renamed and reorganised in relation to one another. The researcher may need to go back to the data and recode the data in relation to the emergent concept summarised in the category or dimension after selecting a category or dimension.

According to Muller & Kogan (2012), Choosing which codes (from the axial codes) to further develop necessitated a selection on which themes to investigate. By analysing the interrelationships that occur among the categories generated in axial coding, the information was retrieved using selective coding (Creswell, 2009).

The chosen coding retains only relevant and applicable variables to the core variables along the procedure in order to generate explicit information. The core category (axial coding) was provided as a declaration of information, which was then categorise and recoded as selective codes. This approach may need to be performed a few times to establish the relationship between codes and arrive at the most credible explanation.

Table 1

Sample of Coding (Open Codes): Issues in Sitting Activity

Index	Respondent 1	Respondent 2
Protocol Time	10:30	14:20
Transcriptions	*"His neck will suffer the longer he sits. The neck cushioning is insufficiently comfy."*	*"Every time he sits, his neck appears to be out of position, resulting in frequent coughing and suffocation."*
Attributes	1. The patient is unable to sit for an extended period of time. 2. The neck cushion is inconvenient to use.	1. The form of the neck cushion did not support the proper neck posture. 2. Coughing and suffocation are caused by poor neck position.
Open Codes: Categories of information	The patient is unable of sitting for long periods of time. Due to an uncomfortable cushion, their neck hurts.	The neck cushion is poorly designed and does not fit the proper neck posture, resulting in frequent coughing and suffocation.
Axial Codes	The patient's neck was hurting due to a lack of ergonomic elements in the neck cushion.	The patient frequently coughing and suffocation due to improper neck posture, resulted from the lack of ergonomic elements in the neck cushion.
Selective Codes	The paddings were not ergonomically designed to compliant with patients' necks (unstable head positioning). Causes frequent coughing and suffocation.	

Findings and Analysis

Table 2 (part 1)

Findings and Analysis of Interviews

Activity of Daily Living	Findings and Analysis	Sample of Direct Quote of The Interview
Sitting	Spend most of the day lying on the bed. - Location: Living room/bedroom - Bed criteria: Conventional bed (pillow as a barrier) /baby bed (with wood barrier) - The pillow being adjusted upwards to let the CP patient watching television. - The ASO will be used for transporting only.	*1. "Since I'll be working in the kitchen all the time, we'll put him on his ASO and leave him in the living room watching tv with an adjusted pillow, where I'll be able to keep an eye on him…."*. (Respondent 6) *2. "We usually just let her lie on the bed, but we make sure there is a barrier in place to keep her from falling out"*. (Respondent 10) *3. "We just used the ASO for transportation and rarely used it in the house"*. (Respondent 7)

Table 2 (part 2)

Findings and Analysis of Interviews

Activity of Daily Living	Findings and Analysis	Sample of Direct Quote of The Interview
Sitting	Headrest Padding - The paddings were not ergonomically designed to compliant with patients' necks (unstable head positioning). Causes frequent coughing and suffocation. - Low quality paddings, foam is not sturdy and too soft. - Cushion/pillow was used as substitute to ensure comfortability.	*1. "His neck will suffer the longer he sits. The neck cushioning is insufficiently comfy."* (Respondent 1) *2. "Every time he sits, his neck appears to be out of position, resulting in frequent coughing and suffocation."* (Respondent 2) *3. "To guarantee a good head posture and comfortability, I constantly have to add a pillow."* (Respondent 3)
	Torso and Waist Padding - The paddings were not ergonomically designed to compliant with patients' torso and waist. The paddings did not hold the torso and waist firmly. - Low quality paddings, foam is not sturdy and too soft. - The CP patient involuntarily tends to slide sideways, downward and forwards. - Affecting the back bones, long term effects: Scoliosis	*1. "The waist paddings are of poor quality... they are not strong and are excessively soft."* (Respondent 3) *2. "He regularly slides sideways because the waist padding is not firm enough."* (Respondent 4)
	Below Limbs Padding -Unstable knee flexion due to the decreased postural control. Low quality paddings, foam is not sturdy and too soft.	*1. "He lost his postural control, which resulted in an unsteady knee flexion."* (Respondent 5)
Transferring	Extremely difficult to manage the ASO for transferring. - Impossible to carry, fold and move the ASO due to heavy and bulky ASO design. Certain parts on ASO need to be setup based on priority to overcome the issue. - Certain parts of the ASO are easily broken or destroyed.	*1. "We, as parents, are growing old and unable to cope with this bulky and heavy design"*. (Respondent 8) *2. "I will not fully configure the ASO because it takes a long time and is difficult to do, and we need to tailor it to the priority."* (Respondent 2) *3. "Every time I tried to prepare the ASO for him, there was a component that would break..."* (Respondent 9)

Table 2 (part 3)

Findings and Analysis of Interviews

Activity of Daily Living	Findings and Analysis	Sample of Direct Quote of The Interview
Transferring	Extremely difficult to transfer the CP patient from the bed, car, and toilet to the ASO or from the ASO to the bed, car, and toilet. Difficult to handle due to regular seizures happened to the patient.	*1. "It's quite difficult to get him from his bed to the toilet or into a car."* (Respondent 3) *2. "She will regularly have a seizure, which makes it difficult for me to transfer her from the bed to the car, or to the bathroom..."* (Respondent 10)
	Parents/guardians manually lift the patient for transferring. Caused back pain and slip disc.	*1. "We, as parents, are growing old and unable to cope with this bulky and heavy design... when I'm performing the transferring, it hurts my back."* (Respondent 8) *2. "Three years ago, I was diagnosed with a slip disc as a result of my frequent manual lifting."* (Respondent 1)
Cleaning/ Bath	Due to a bulky and heavy design of ASO, the CP patients were being lifted by parents/guardians to the toilet/bathroom.	*1. "I have to manually lift her to the toilet since the ASO is heavy and bulky."* (Respondent 10) *2. "I can't work with the heavy and bulky ASO, so I'll just lift him to the restroom manually."* (Respondent 3)
	Cleaning/ baths the CP patients in the toilet was found to be very challenging. - The process of cleaning/bath will be much more difficult and exhausted due to patient restraining or having a seizure. This resulted in a slippery and a series of falls. - Parents/guardians preferred to do the cleaning/bath process once a day while the patient is lying on the bed. - Pampers, water spray, water in the basin and wet napkin were used during the process (on the bed). Resulted in hygiene issues and bacterial infections among the patients.	*1. "She will be restraining because of the seizure that occurs regularly, especially while cleaning or having a bath, and it is risky since the tiles are slippery... me and her always fall in the bathroom."* (Respondent 10) *2. "I'd rather clean him while he's on the bed, once a day so I used the cleaning wipes... However, there will be issues with hygiene and bacterial infection from time to time."* (Respondent 7) *3. "I usually put on a pampers on him and clean him with a water spray or a wet napkin."* (Respondent 5)

Table 2 (part 4)

Findings and Analysis of Interviews

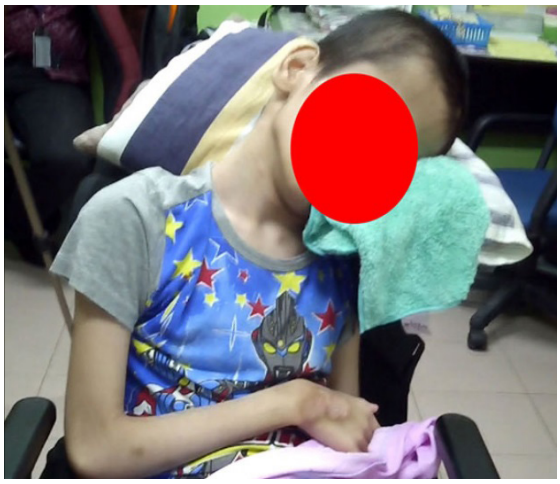
Activity of Daily Living	Findings and Analysis	Sample of Direct Quote of The Interview
Cleaning/ Bath	Plastic chair/netted chair/ lazy chair was used in the cleaning/ bath process.	*1. "To clean my son, my spouse placed a lazy chair in the bathroom."* (Respondent 2) *2. "We purchased a netting chair and put it in the bathroom for him."* (Respondent 3)
	The current ASO is not water-resistant	*1. "I can't use water on the ASO since it's not water resistant."* (Respondent 2) *2. "I tried to clean him on the ASO, but it ended up being a bad idea because the water ruined the seat."* (Respondent 5)
	The current ASO have no options available to physically positioned/ adjusted the CP patient to compliant the cleaning/bath process.	*1. "Cleaning him on the ASO is difficult since there is no way to adjust their position on the ASO."* (Respondent 7)
Dressing/ Undressing	Extremely difficult to dressing/ undressing CP patient in sitting position on the ASO. - CP patient tends to restrain or having seizure during the process. - As an alternative, most of parents/ guardians dressing or undressing the CP patient on the bed	1. *"I occasionally dressed or undressed her on the ASO as well, but it is difficult due to restraining because she has seizures regularly. Hence, I prefer to do it on the bed"* (Respondent 10) 2. *"It was much more convenient for me to dress or undress him while he was resting on the bed."* (Respondent 6)
Feeding	Severe level of spastic CP patient feed on liquid milk through machine attached to the ASO for every 2 hours. Milk is given to the CP patient on a daily basis.	1. *"He cannot eat the regular food, hence on daily basis I feed him milk, which is quite expensive."* (Respondent 1) 2. *"The machine is on the side of the ASO."* (Respondent 2)
	Intermediate level of spastic CP patient feed on soft food with the help from parents/guardians	1. *"She can eat the soft regular food, just the same as ours"* (Respondent 10) 2. *"He can eat the soft regular food, but with our help to feed him."* (Respondent 5)

Table 2 (part 5)
Findings and Analysis of Interviews

Activity of Daily Living	Findings and Analysis	Sample of Direct Quote of The Interview
Feeding	Parents/guardian are not having ergonomic issue in feeding the CP patient on the ASO	1. *"When it comes to feeding him, I don't have any issues."* (Respondent 6)
Sleeping/ Napping	Regularly sleeping on the bed	1. *"Normally, I will place him in the bed with me at night."* (Respondent 8) 2. *"At night, he'll sleep on the bed."* (Respondent 2)
	Occasionally taking a nap on ASO when they were outside. - ASO cannot be adjusted to meet comfortable napping position - The body and waist paddings fail to firmly support the patient's body when sleeping, resulting in sideways or downwards slipping. - The neck paddings fail to conform to patients' necks when sleeping, resulting in repeated coughing and suffocation - Due to decreased flexor of the hip and knee, patient lost the postural control, and their legs are not in comfortable position.	1. *"He will take a sleep on the ASO from time to time, especially when it is outdoors. However, he finds it difficult to sleep on the ASO since he keeps falling sideways or downwards."* (Respondent 4) 2. *"His neck will suffer the longer he sits. The neck cushioning is insufficiently comfy."* (Respondent 1) 3. *"Every time he sits, his neck appears to be out of position, resulting in frequent coughing and suffocation."* (Respondent 2)

Finding and Analysis 1: Issues in Sitting Activity

Based on the interview, the majority of CP patients spend the significant amounts of time lying on the bed in the living room or the bedroom. As indicates by the parents/guardians, the ASO is only used for transportation purposes. Some parents/guardians will lift the pillow a bit higher to allow CP patients to watch television or to improve their comfort (Figure 5). A baby bed with a wood barrier was used to keep the CP patients from falling out of bed. In the case of a conventional bed, the parents/guardians would use a pillow to provide a barrier. When seated on the ASO, most parents/guardians report that the headrest padding is not comfortable for CP patients. Parents/guardians emphasized the stiffness of the headrest padding. The researchers have observed that the shape and size of the headrest paddings are not ergonomically designed to compliant with patients' necks, head and jaws, and low-quality foam was used in the design. Due to these issues as stated by the parents/guardians, some CP patients had a regular series of severe coughing and suffocation. Many parents/guardians covered the headrest padding with additional cushion or pillow as a solution. In addition, the researchers have observed that most CP patients appeared to involuntarily slide sideways, downward and forwards while seated on the ASO. The condition arose due to the inadequate design and structure of the torso and the waist paddings, which did not secure the patient's body and waist tightly. As a result, some CP patients have developed scoliosis. In particular, due to the precarious flexion of the knee, the lower limbs of the CP patients were not in a stable position and causes comfortlessness.



» **Figure 5:** *Additional pillow added to the headrest padding*

Finding and Analysis 2: Issues in Transferring Activity

Transferring the CP patient from the bed, car, and toilet to ASO was found to be extremely difficult, according to the interview. The researchers have observed that the situation arose as a result of the current ASO's heavy and bulky design, which made it challenging to fold and move the ASO. In order to overcome the issue, certain parts on ASO must be attached or detached according to priority. Nevertheless, the researchers also discovered that due to repeated folding, certain parts of the current ASO are easily broken or destroyed. As an alternative, the majority of parents and guardians manually lift the CP patients for transferring but exposing themselves to back pain and disc slippage.

Finding and Analysis 3: Issues in Cleaning/Taking Bath Activity

Based on the interview, cleaning/ baths the CP patients in the toilet was found to be very challenging. As indicates in the previous section, due to a bulky and heavy design of ASO, most of the parents and guardians them-

selves lift the CP patients for transferring, which includes to the toilet/bathroom as well. In the toilet/bathroom, some of the parents/guardians will put the CP patients on plastic chair, netted chair or lazy chair. However, due to patient restrained or seizures, the process of cleaning/bath will be much more difficult, resulted in a slippery and a series of falls. Thus, some of the parents and guardians preferred to do the cleaning/bath process while the CP patient is lying on the bed. Diapers, water spray, water in the basin and wet napkin were used as an alternative when doing the cleaning/bath activity on the bed. However, this resulted in hygiene issues among the patients, leading to bacterial infections and other health implications. Based on the observation, the researchers discovered that due to non-water-resistant characteristics, the current ASO are not functionally appropriate for cleaning/taking baths, and there are no alternatives available to physically position/adjust the CP patient to comply with the cleaning/bath procedure.

Finding and Analysis 4: Issues in Dressing/Undressing Activity

Based on the interview, most of the parents/guardians indicates that it was difficult to dressing or undressing the CP patient when they are in sitting position on the ASO, and they tend to restrain or having seizure during the process. As the CP patient growing and become stronger, the restrain give a difficulty for the parents/guardians to handle them. As an alternative, the process of dressing or undressing the CP patient was executed on the bed.

Finding and Analysis 5: Issues in Feeding

Based on the interview, CP patients with a severe level of spastic condition feed on liquid milk via a system connected to the ASO every 2 hours (see Figure 6), while CP patients with an intermediate level of spastic condition feed on soft food with the aid of parents/guardians, according to the interview and observation. In terms of ergonomics, feeding the CP patient on the ASO is not a problem for the parents or guardians.

» **Figure 6:** *Liquid milk feeding machine connected to the ASO.*

Finding and Analysis 6: Issues in Sleeping/Napping Activity

According to the interview, CP patients sleep in their beds regularly and only use ASO to nap while they are outside, such as for a clinic visit. The ASO, however, cannot be adjusted to reach a comfortable napping position, based on the observation. As indicates by parent/guardians, the neck paddings fail to adhere to patients' necks when napping on the ASO, resulting in repeated coughing and suffocation. Furthermore, when napping on the ASO, the body and waist paddings struggle to firmly support the patient's body, resulting in sideways or downward sliding. Nonetheless, due to decreased flexor of the hip and knee, patient lost the postural control, and their legs are not in comfortable position while sleeping on ASO.

Discussion

Based on the previous literature, a study conducted by Angsupaisal et al. (2017), Bolas & Boyle (2017), Chung et al. (2008); Ries, Novacheck & Schwartz (2014), Rigby, Ryan & Campbell (2009), Ryan (2016), Sahinoglu, Coskun & Bek (2017), and Vekerdy (2007) have established that the ASO improves the occupational performance of CP patients to become more active during the intervention for a longer periods. Furthermore, the ASO allows the face-to-face social interactions, leading to increased sociability with family and friends. However, the use of ASO can be technically challenging for parents/guardians, as it did not provide adequate support or the stability required by the anthropometrics of Malaysian CP patients (Hui et al., 2011). Nevertheless, the average cost of funding for a patient's needs including purchasing the existing ASO are highly expensive especially for the bottom millions (Kamaralzaman et al., 2018). In relation to this current research objective, the results of the assessment have shown a multitude of issues faced by the parents/guardians in taking care of the CP patient especially during sitting, transferring, cleaning/bath and sleeping/napping, including the analysis of the ergonomic issues due to the technical aspect in the existing ASO. Furthermore, a lack of expertise and experience in dealing with CP patients among parents/guardian exacerbated the problems. Hence, a few design criteria were outlined with aims to improve the ASO design (see Table 3).

A high density of adjustable/flexible headrests with the shape and design that corresponds to the physical condition of the head, neck, and jaw will be implemented for the development of ASO design. These criteria are to ensure that CP patient's head can be placed in a comfortable resting position, to avoid frequent coughing and suffocation, to provide comfort, and to encourage positive movements of CP patient’s head and neck.

The ASO will also feature high-density body and waist padding, as well as lumbar protection, backrest and side bolsters, and a four-point safety belt.

Table 3

Design Criteria to Improve the ASO Design Development

Design Criteria	Descriptions
High density of adjustable/ flexible headrest with the shape and design corresponds to the physical condition of the head, neck and jaw.	i. Aim to comfortably rest CP patient's head and prevent the tendency of regular coughing and suffocation. ii. Aim to provide comfort and encourage positive movements of CP patient's head and neck.
High density of body and waist padding with lumbar support, backrest and side bolster, and 4-point safety belt.	i. Aim to stabilize the CP patient's body comfortably and firmly. ii. Aim to prevent the CP patient's tendency from involuntary sliding to the sideways/ downwards/ forward. iii. Aim to safely restraint the CP patient when having regular seizures.
Adjustable lower limbs supporter and separator	i. Aim to stabilize and solve the unstable knee flexion of the CP patient's lower limbs.
Simple folding mechanism and space saving, with lighter and durable material used	i. Aim to provide an easy and space saving storage through a simple folding mechanism. ii. Aim to provide a lighter ASO with a quality material used.
Lifting and Transferring assist features	i. Aim to enhance safety elements for both parents/ guardians during lifting and transferring process. ii. Aim to provide a proper lifting and transferring process from the bed, car, and toilet to the ASO or from the ASO to the bed, car, and toilet.
Easy cleaning mechanism with water flowing and resistant features.	i. Aim to reduce the needs of lifting and transferring to the toilet by providing an alternative to do the simple cleaning process while sitting on the ASO. ii. Aim to ensuring a good hygiene
Visually aesthetic	i. Aim to boost confidence level, reduce the detrimental effect, tension and stress among parents/guardian and patients through the quality of aesthetic appeal in ASO design. ii. Aim to the provide appropriate comfort of the patients' psychological and physiological response.

These criteria are intended to keep the CP patient's body stable and secure while sitting, to avoid the CP patient's involuntary sliding to the side, downwards, or forward, and to securely restrain the CP patient while having recurrent seizures. Furthermore, an adjustable lower limbs supporter and separator will be included to stabilize and overcome the CP patient's lower limbs' unstable knee flexion. Nevertheless, an easy folding feature with a lighter and durable material will be introduced as well, with the goal of providing a lighter ASO with high quality material and efficient space saving purposes. With regards to ensure the safety for both patients and parents/guardians, lifting and transferring assist feature will be implemented to provide a proper lifting and transferring process from the ASO to the bed, car, and toilet or from the bed, car, and toilet to the ASO. Finally, the ASO will be fitted with an easy cleaning system that includes water flowing and resistant features, with the goals of reducing the need for lifting and moving to the toilet, providing an alternative to doing the basic cleaning process while sitting on the ASO, and maintaining good hygiene.

Conclusion

Based on the findings and analysis, the aims of this study have been met; 1) to determine the technical difficulties faced by the parents/guardians in taking care of the CP patient; and (2) to analyse the ergonomic issues due to the technical aspect in the existing ASO support. Based on the results of interview and observation, it can be concluded that there are various ergonomic and technical issues in the existing ASO including a series of challenges experience by the parents/guardians in taking care of the CP patient. Furthermore, throughout the research process, the implementation of ergonomics ergo-system and the framework of design needs assessment is beneficial to incorporate the CP's orthotic needs. The implication of this study helps the researchers to establish significant design criteria for the development of ASO designs in the near future, which in line with one of the Six Strategies Trusts in Eleventh Malaysia Plan (RMK-11); to enhance the well-being of Malaysian people (particularly in the B40 group) by providing better healthcare.

Acknowledgement

Our special thanks to all respondents who participate in the study, including Prof. Dr. Abdul Razak Sulaiman, Dr. Emil Fazliq Mohd, Dr Abdul Hakim Fikry and Dr Mohd Hafizuddin for the help and support rendered during the data collection process.

Funding

This research has been funded by Fundamental Research Grant Scheme (FRGS), FRGS; 203.PSENI.6712030.

References

Angsupaisal, M., Dijkstra, L.-J., la Bastide-van Germert, S., van Hoorn, J. F., Burger, K., Maathuis, C. G. B. & Hadders-Algra, M. (2017) Best seating condition in children with spastic cerebral palsy: One type does not fit all. *Research in Developmental Disabilities.* 71, 42–52. Available from: doi: 10.1016/j.ridd.2017.09.016

Austin, J. & Delaney, P.F. (1998) Protocol analysis as a tool for behavior analysis. *The Analysis of verbal behavior.* 15 (1), 41–56. Available from: doi: 10.1007/BF03392922

Bolas, J. & Boyle, P. (2017) Parental views regarding seating and participation for young children with cerebral palsy. *Journal of Occupational Therapy, Schools, and Early Intervention*. 10 (3), 254–265. Available from: doi: 10.1080/19411243.2017.1325814

Bridger, R. (2008) *Introduction to ergonomics.* Boca Raton, CRC Press.

Chung, J., Evans, J., Lee, C., Lee, J., Rabbani, Y., Roxborough, L. & Harris, S. R. (2008) Effectiveness of adaptive seating on sitting posture and postural control in children with cerebral palsy. *Pediatric physical therapy: the official publication of the Section on Pediatrics of the American Physical Therapy Association.* 20 (4), 303–317. Available from: doi:10.1097/PEP.0b013e31818b7bdd

Colver, A., Fairhurst, C. & Pharoah, P. O. D. (2014) Cerebral palsy. *The Lancet.* 383 (9924), 1240–1249. Available from: doi: 10.1016/S0140-6736(13)61835-8

Creswell, J. W. (2009) *Research Design: Quantitative, Qualitative, and Mixed Methods Approaches.* Thousand Oaks, Sage Publications.

Cross, N. (2001) Designerly Ways of Knowing: Design Discipline Versus Design Science. *Design Issues.* 17 (3), 49–55. Available from: doi: 10.1162/074793601750357196

Glaser, B. G. & Strauss, A. L. (2017) *Discovery of grounded theory: Strategies for qualitative research.* Abingdon, Routledge.

Hughes, C. X., Gardner, R., Pyman, J., Toomey, K. & Gargan, M. F. (2012) Orthopaedic assessment and management of cerebral palsy. *Orthopaedics and Trauma.* 26 (4), 280–291. Available from: doi: 10.1016/j.mporth.2012.05.001

Hui, L. S., Yian, C. S., Razak, H., Abdullah, M. R., Chang, W. S. & Hock, T. T. (2011) Locally Made Paediatric Rehabilitation and Seating Systems for Cerebral Palsy Children in Sarawak. *International Journal of Public Health Research*, 146–151.

Kamaralzaman, S., Ying, T. C., Mohamed, S., Toran, H., Satari, N. & Abdullah, N. (2018) The economic burden of families of children with cerebral palsy in Malaysia. *Malaysian Journal of Public Health Medicine.* 1, 156–165.

Kamil, M. J. M. & Sani, M. N. A. (2021) The Challenges and Initiatives of Teaching Product Design's Course Online During the COVID-19 Pandemic in Malaysia. *Asia Pacific Journal of Educators and Education.* 36 (1), 113–133.

Kamil, M. J. M., Hua, C. E. & Sani, M. N. A. (2022) Adaptation of smart-object dimensions in the product design process to reduce household food waste. *Journal of Graphic Engineering and Design.* 13 (3), 5–17.

Kamil, M. J. M., Shi, S. M. L. & Sani, M. N. A. (2020) Re-assessing the Design Needs of Trans-Radial Amputees in Product Design Innovation. *Wacana Seni Journal of Arts Discourse.* 19, 61–71. Available from: doi: 10.21315/ws2020.19.5

Kamil, M. J. M., Zainal Abidin, S. & Hassan, O. H. (2018) The Investigation of Designers' Reflective Practice Activity Using Verbal Protocol. In: DS93: *Proceedings of the 20th International Conference on Engineering and Product Design Education, E&DPE, 6-7 September 2018, London, United Kingdom*. Glasgow, The Design Society. pp. 363–368

Kamil, M. J. M., Zainal Abidin, S. & Hassan, O. H. (2019a) *Assessing Designers' Perception, Analysis, and Reflective Using Verbal Protocol Analysis.* In: Chakrabarti, A. (ed.) Research into Design for a Connected World. Singapore, Singapore, Springer Singapore, pp. 51–61.

Kamil, M. J. M., Zainal Abidin, S. & Hassan, O. H. (2019b) *Assessing the Attributes of Unconscious Interaction Between Human Cognition and Behavior in Everyday Product Using Image-Based Research Analysis*. In: Chakrabarti, A. (ed.) Research into Design for a Connected World. Singapore, Singapore, Springer Singapore, pp. 63–73.

Matos, D., Ferreira, A. M., Pinho, A. M. & Martins, J. P. (2014) Contribution of Design in the Developmental Process of External Prosthetic Medical Devices. In: *Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics, AHFE 2014, 19-23 July 2014, Kraków, Poland*. Leesburg, Noldus Information Technology. pp. 2482–2487.

Muller, M. J. & Kogan, S. (2012) *Grounded Theory Method in HCI and CSCW.* Cambridge, IBM Center for Social Software, pp. 1–46.

Polhan, N., Charatrungolan, T., Dacharux, W., Siriwatsopon, J. & Guerra, G. (2019) Provisional outcomes of affordable custom wheelchair seating for an individual with cerebral palsy: Case report. *Chiang Mai University Journal of Natural Sciences.* 18 (3), 305–312. Available from: doi: 10.12982/CMUJNS.2019.0021

Ries, A. J., Novacheck, T. F. & Schwartz, M. H. (2014) A data driven model for optimal orthosis selection in children with cerebral palsy. *Gait and Posture.* 40 (4), 539–544. Available from: doi: 10.1016/j.gaitpost.2014.06.011

Rigby, P. J., Ryan, S. E. & Campbell, K. A. (2009) Effect of Adaptive Seating Devices on the Activity Performance of Children With Cerebral Palsy. *Archives of Physical Medicine and Rehabilitation.* 90 (8), 1389–1395. Available from: doi: 10.1016/j.apmr.2009.02.013

Ryan, S. E. (2016) Lessons learned from studying the functional impact of adaptive seating interventions for children with cerebral palsy. *Developmental Medicine and Child Neurology*. 58 (S4), 78–82. Available from: doi: 10.1111/dmcn.13046

Sahinoglu, D., Coskun, G. & Bek, N. (2017) Effects of different seating equipment on postural control and upper extremity function in children with cerebral palsy. *Prosthetics and Orthotics International.* 41 (1), 85–94. Available from: doi: 10.1177/0309364616637490

Saldaña, J. (2009) *The coding manual for qualitative researchers.* Thousand Oaks, Sage Publications.

Sani, M. N. A., Kamil, M. J. M., Azahari, B. & Sulaiman, A. R. (2019) The Assessment of the Clubfoot Children's Orthotic Need for the Development of the Foot Abduction Orthosis (Fao) Prototype Design. *International Journal of Advances in Science, Engineering and Technology.* 7 (1), 20–24.

Tan, K. L. & Yadav, H. (2008) Assessing the development of children with disability in Malaysia. *Medical Journal of Malaysia.* 63 (3), 199–202.

Tharshini, N. K., Ibrahim, F., Amin, A. S. & Zakaria, E. (2016) Cabaran Golongan Ibu dalam Penjagaan Anak Kurang Upaya (Cerebral Palsy). The Cerebral Palsy (Spastic) Children's Association of Penang. *Jurnal Pembangunan Sosial.* 19 (1), 69–82.

Vekerdy, Z. (2007) Management of seating posture of children with cerebral palsy by using thoracic-lumbar-sacral orthosis with non-rigid SIDO® frame. *Disability and Rehabilitation.* 29 (18), 1434–1441. Available from: doi: 10.1080/09638280601055691

Zainal Abidin, S., Christoforidou, D. & Liem, A. (2009) Thinking and re-thinking verbal protocol analysis in design research. In: Norell Bergendahl, M., Grimheden, M., Leifer, L., Skogstad, P. and Lindemann, U. (eds.) *Proceedings of the 17th International Conference on Engineering Design, ICED'09, 24-27 August 2009, Stanford, California.* pp. 1–12.

Original scientific paper http://doi.org/10.24867/JGED-2023-4-025

Comparison of colourimetric results obtained by spherical and spectrophotometer with directional geometry on samples with extreme UV varnish application

ABSTRACT

It is known that gloss has a significant impact on colour measurement. The UV varnish used for surface finishing, spot effects, as well as special effects, such as 3D effects and formation of Braille, has a pronounced gloss effect. In this work, a comparison of the spectrophotometer measurement geometry influence on the colour measurement of an unprinted PVC sample covered with UV varnish was done. UV varnish was applied successively in layers, and patches with different number of varnish layers, from 1 to 12, were formed. Two spectrophotometers with different measurement geometries were used for the measurement: Konica Minolta CM-2600d with d/8 measurement geometry, with spectral reflection included and excluded, and different measurement aperture 3 and 8 mm, and X-Rite eXact with 45/0 measurement geometry. By comparing the measurements, it was established that there is a significant difference in the measured values between different measuring device geometries on the given samples, and that the number of UV varnish layers has a significant influence on this difference.

KEY WORDS
Spectrophotometer geometry, UV varnish, plastic, colour difference

Đorđe Vujčić [1]
Sandra Dedijer [2]
Mladen Stančić [1]
Branka Ružičić [1]
Igor Majnarić [3]

[1] University of Banja Luka, Faculty of Technology, Graphic engineering, Banja Luka, Bosnia and Herzegovina
[2] University of Novi Sad, Faculty of Technical Sciences, Graphic Engineering and Design, Novi Sad, Serbia
[3] University of Zagreb, Faculty of Graphic Arts, Graphic engineering, Zagreb, Croatia

Corresponding author:
Đorđe Vujčić
e-mail:
djordje.vujcic@tf.unibl.org

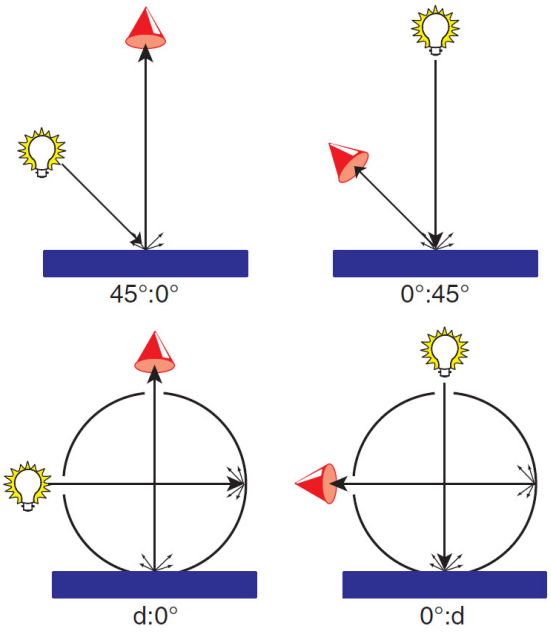
First received: 17.2.2023.
Revised: 13.4.2023.
Accepted: 26.4.2023.

Introduction

Spectrophotometers represent colour measuring instruments which are the most reliable and precise. Different factors influence perceived colour; thus, it can be concluded that also different measuring conditions influence measured colour. The illumination condition and viewing angle are most important of them. Therefore, measuring geometry have a great impact on measurement results (Dalal & Natale–Hoffman, 1999). It has been shown in some previous studies that measured results can significantly differ among different measuring geometries, depending on the characteristics of measured sample (Dalal & Natale–Hoffman, 1999; Kandi, 2011; Milić, Novaković & Kašiković, 2011).

Two most common measuring geometries are directional and diffuse. There are two types of directional geometry: 45/0 and 0/45 (figure 1 a and b). The first number stands for illumination angle, and second for optics. Since the optics are positioned at an angle of 45 degrees related to the illumination, they do not detect specular

reflection. In case of diffuse geometry, there are two common types: d/8 and 8/d (figure 1 c and d). The letter d stands for diffuse, which means that illumination or viewing is not directional but diffuse. This is achieved with use of an integrating sphere. Number 8 represents the angle of optics. In first case, d/8, instrument illuminates the sample from scattered directions and reflected light is detected at an 8-degree angle. In second case, 8/d, instrument illuminates the sample at an 8-degree angle and reflected light is detected from scattered directions. In this kind of geometry, specular port can be used, in order to exclude specular component. Therefore, with this kind of instrument two modes of measurement can be done – the specular component included (SCI) and the specular component excluded (SCE). With mode SCE, the idea is to exclude the specular component, and obtain measurement similar to 0/45 geometry. Since the size of the specular port is limited, sometimes it is not able to allow all of the gloss to escape, thus measurements between 0/45 geometry and diffuse geometry with the specular component excluded may vary (Kandi, 2011; Milić, Novaković & Kašiković, 2011; Yuan, Yan & Jin, 2013; Berns, 2019). Size of specular port and integrating sphere is not specified by CIE, which leads to inconsistency between measurement results of two different instruments (Yuan, Yan & Jin, 2013).



» **Figure 1:** *Spectrophotometer measuring geometries (a) 45/0, (b) 0/45, (c) d/0 and (d) 0/d (Berns, 2019: p.117)*

Both geometries have some advantages and are used for different purposes. Since the observed and measured sample is another factor that has great influence on measurement, type of selected geometry depends on it. In case of samples with matte, regular surface, reflected light is almost same at all angles, thus results obtained with diffuse, both SCI and SCE, and directional geometry would be almost equal. But, in case of gloss or surfaces that are not flat and regular, diffuse geometry shows its supremacy (Milić, Novaković & Kašiković, 2011).

Colour that is measured or perceived is influenced by amount of detected light that is reflected from surface (Dalal & Natale–Hoffman, 1999). It is known that an object's gloss greatly influences perceived colour (Dalal & Natale–Hoffman, 1999; Luo & Cui, 2009). Assessment of samples with different gloss levels is challenging, since agreement between visual and instrumental assessment is not clearly defined. Unlike a measuring instrument, a person can very simply change the observation conditions, as well as the viewing angle, to give a visual assessment of the sample. In this way, a person can simultaneously consider both the gloss and the colour itself. With measuring instruments, the lighting and observation conditions are fixed, which leads to the fact that the instrument does not observe the sample in the way we see it (Datacolour, n.d.). This is summarized in Table 1.

Table 1

Comparing readings with different types of measuring geometries or assessments on matte, regular surface, and gloss and/or irregular surface

Type of measuring geometry or assessment	Matte and regular surface	Gloss and/or irregular surface
Directional geometry	Consistent readings	Great variations in readings
Diffuse geometry	Consistent readings	Consistent readings
Directional vs. diffuse geometry	Nearly identical readings	Great variations in readings
Visual vs. instrumental assessment	Good agreement	Agreement not clearly defined

When observing samples, person usually rotates the sample to avoid specular reflection. If we take that into account, the measuring geometry of 45/0 and 0/45 is closer to human colour vision. It is generally accepted that these measurement geometries have a better agreement with the visual assessment of glossy samples. Still, these geometries are not always best solution. They showed poor performances for computer formulation and correction applications. Also, there is a problem for making corrections of batch. These instruments include gloss differences in measurement results. In case of gloss variations from batch to batch, gloss differences will be taken as colour differences (Datacolour, n.d.).

When comparing objects that have same colour, but different gloss characteristic, matte object seems to

have less intense colour, and its lightness is higher, while chroma is lower, compared to corresponding gloss object (Dalal & Natale–Hoffman, 1999; Luo & Cui, 2009). Gloss also has major effect on colour measurement. Small differences in viewing geometry can lead to significant variations in colourfulness, particularly lightness, while change in hue is not so noticeable (Luo & Cui, 2009; Yuan, Yan & Jin, 2013). When measured using 45/0 geometry, colours seem more saturated. This is not so obvious in case of colours that have low chroma and for saturated colours (yellows) of high reflectance. Differences in saturation are largest in case of dark colours (Knowles Middleton, 1953). For material with same colour but different gloss, diffuse measuring geometry, mode SCI, obtains the uniform results. SCI geometry covers up gloss differences, and shows real colour difference (Datacolour, n.d.; Randall, 1998; Yuan, Yan & Jin, 2013). But results obtained with 45/0 measuring geometry will show pretty large colour differences (Randall, 1998). Diffuse instruments detect all of the reflected light; thus, the measured colour is independent of sample gloss. Instruments with 0/45 geometry, quite the opposite, do not detect nearly all specular reflected light, thus the measured colour is quite dependent on the sample gloss (Dalal & Natale–Hoffman, 1999).

UV varnish can be applied directly to substrate, even nonabsorbent, in order to achieve different gloss levels, tactile finishes or drip-off effects. It is used more and more for achieving additional value, especially as spot UV varnish on packaging. The goal is to improve brilliance and glossiness of the printed media underneath. This can be achieved with just a few µm of UV varnish. When the goal is to achieve tactile effects, like embossed texture, layer of applied varnish needs to be thicker, in the range from 20 to 200 µm. This can be reached by applying number of UV varnish layers, one on top of the other. Since UV varnish can be instantly cured after printing, these layers can be printed on the same spot. In this way, UV varnish is also used for printing braille letters, and also illustrations in braille books, signage and labeling in galleries and museums, etc. (Vujčić et al., 2021).

There are some researches that investigated influence of UV varnish on optical characteristic of substrate. They showed that applied UV varnish has impact on colour difference (Majnarić, Bolanča Mirković & Golubović, 2012; Galić, Ljevak & Zjakić, 2015).

This paper investigates influence of different measuring geometries on the results of colour measurement for samples with different number of applied varnish layers. Also, influence of number of applied varnish layers on measurement difference between geometries was investigated.

Methods and Materials

Measurements were done on DuraGo PVC plastic (Tekra, LLC., USA) samples 0,5 mm thick. Samples were unprinted and covered with UV varnish on printing machine VersaUV LEC300 (Roland DG Corporation, Japan, 2011), in different number of layers, from 1 to 12 (Figure 2). Liquid UV varnish was transferred directly to the printing substrate, in this case a PVC plastic, and then cured with UV light. ECO-UV varnish, EUV-GL v.4, the following compositions were used (Roland, 2019): 1,6-Hexamethylene diacrylate 20-30%, 2-Methoxyethyl acrylate 20-24%, Benzyl acrylate 10-25%, N-Vinyl caprolactam 10- 20% and Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 5-10%. The printing was done from 1 to 12 layers, so colour difference could be monitored with every additional layer of varnish. Final 12 layers of varnish were applied, since previous research showed that with this number of layers of UV varnish legible Braille is obtained (Miloš, Vujčić & Majnarić, 2021). Gloss mode (drying with one UV lamp) was used for printing. The print resolution was 740 x 1440 dpi. The direction of printing was set to unidirectional, and rasterization was done according to the dither method. Printing was done in high quality mode- higher amount of varnish and resolution, and lower speed. It is printed using a DX4 Epson piezo Inkjet head with dot size of 3,5 pL (Format Media Ltd., 2010). After 5 layers, the height of the head was changed to a higher level.

During exposition to UV light and polymerization process printed UV varnish turns yellow. It is due to photoinitiators, which become yellow during the curing process and exposition to UV light, and with more varnish layers the yellowness is more pronounced. It can be noticed in Figure 2. UV varnish was printed with the printing machine VersaUV LEC300, which uses LED UV lamps for curing. The deficiency of exposition to the UV light spectrum emitted by these lamps is more pronounced yellowness of UV varnish.

» **Figure 2:** *Scanned sample*

After that, the Lab values of the given samples, before and after applying different number of layers of UV varnish, were measured. Colour characterization was done with two types of spectrophotometers:

- Konica Minolta CM-2600d (Konica Minolta Sensing, Inc., Japan)- d/8 diffuse geometry with the measurement aperture 3 mm and 8 mm and two measurement modes:

SCI- the spectral component included and SCE- the spectral component excluded and

- X-Rite eXact (X-Rite, Inc., USA)- 45/0 geometry with the measurement aperture 2 mm.

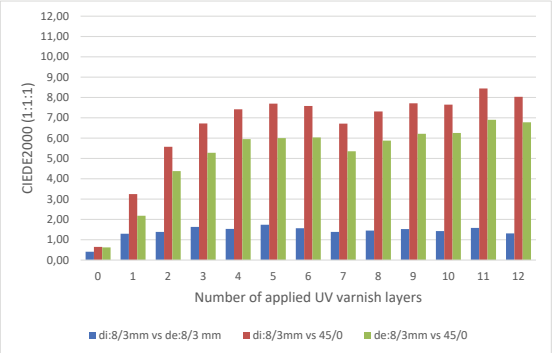
The colour coordinates of the samples were obtained using standard illumination D50 and standard observer angle 2º, according to ISO 3664:2009 (International Organization for Standardization, 2009). Measurements were repeated 10 times for every sample.

Results obtained with two kinds of geometry were compared. The colour difference between measurements done with d/8, SCI and SCE, measurement aperture 3 and 8 mm, and 45/0 spectrophotometer was calculated for each sample, using the CIEDE2000 (1:1:1) colour difference formula (Luo, Cui & Rigg, 2001). For easier distinction of different apertures and modes, in case of diffuse measuring geometry, following marks were used: di:8/3mm, where d stands for diffuse, i for SCI, 8 for angle and 3mm for measurement aperture; de:8/3mm, where e stands for SCE.

Results and Discussion

In Figure 3. are presented colour difference values of measured sample before and after printing different number of UV varnish layers, from 1 to 12, measured with di:8/3mm, de:8/3mm and 45/0 measuring geometry. From the presented results, it can be noticed that spectrophotometer measurement geometry influences the colour coordinates of UV varnished samples. Differences between measured Lab values of unprinted plastic, before applying UV varnish, are in range from 0.41 to 0.65. After applying UV varnish, differences between measurements are higher, especially between di:8/3mm and 45/0 geometries. When comparing di:8/3mm or de:8/3mm with 45/0, these differences are significantly higher with every additional layer of varnish, while they are not changing significantly between di:8/3mm and de:8/3mm. Differences between measured Lab values with di:8/3mm and de:8/3mm are changing in range from 1.29 to 1.74 after applying different number of UV varnish layers, from 1 to 12, and these changes are not regular, but they are also not significant.

Differences between di:8/3mm or de:8/3mm with 45/0 are much higher. They are a little bit higher between di:8/3mm and 45/0. After first and second layer of UV varnish, difference between measurements is extremely higher, and after applying third layer of UV varnish difference is not changing drastically. With every additional layer of UV varnish, there are some changes in calculated colour difference values, but they are not significant. This is case for both di:8/3mm and de:8/3mm measurements compared to 45/0.



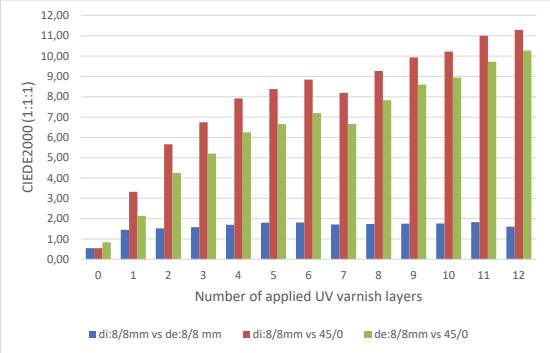
» **Figure 3:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8º spectrophotometer with measurement aperture 3mm, both SCI and SCE, and 45º/0º spectrophotometer measurements*

In Figure 4. are presented colour difference values of measured sample before and after printing different number of UV varnish layers, from 1 to 12, measured with di:8/8mm, de:8/8mm and 45/0 measuring geometry. From the presented results, it can be noticed, again, that spectrophotometer measurement geometry influences the colour coordinates of UV varnished samples. Differences between measured Lab values of unprinted plastic, before applying UV varnish, are in range from 0.55 to 0.84. After applying UV varnish, differences between measurements are higher, especially between di:8/8mm and 45/0 geometries. When comparing di:8/8mm or de:8/8mm with 45/0, these differences are significantly higher with every additional layer of varnish, while they are not changing significantly between di:8/8mm and de:8/8mm. Differences between measured Lab values between di:8/8mm and de:8/8mm are changing in range from 1.45 to 1.83 after applying different number of UV varnish layers, from 1 to 12, and these changes are not regular, but they are also not significant.

Differences between di:8/8mm or de:8/8mm with 45/0 are much higher. They are higher between di:8/8mm and 45/0. After first and second layer of UV varnish, difference between measurements is extremely higher, and after applying third layer of UV varnish difference is not changing drastically, and with every additional layer of UV varnish, this difference is smaller. This is case both for di:8/8mm and de:8/8mm measurements compared to 45/0. Changes are smaller for de:8/8mm measurements, but trend is same for both types of measurements – di:8/8mm and de:8/8mm.

There is some unusual colour difference drop at 7 layers of UV varnish, and there was no logical explanation for this occurrence. Maybe it could be related to the position of patch with 7 layers of UV varnish. The test form was printed in the way that in one row were printed patches with 1 to 6 layers, and in second row

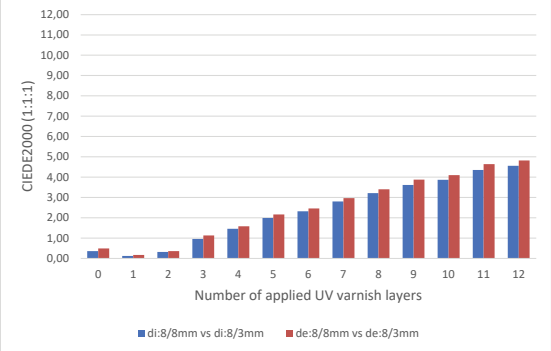
were patches with 7 to 12 layers of UV varnish (Figure 2). Although, there is no certain connection between position and measured values. Also, compared to measurements done with measurement aperture 3mm, difference is much higher, and it also increases, almost linear, with every additional layer of UV varnish.



» **Figure 4:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8° spectrophotometer with measurement aperture 8mm, both SCI and SCE, and 45°/0° spectrophotometer measurements*

Finally Figure 5. presents colour difference values of measurements with di:8/3mm and de:8/3mm compared to di:8/8mm and de:8/8mm. From the presented results, it can be noticed, that spectrophotometer measurement aperture also influences the colour coordinates of UV varnished samples. Difference between measured Lab values of unprinted plastic, before applying UV varnish is 0.36 for SCI and 0.49 for SCE. After applying first and second layer of UV varnish, differences are a little bit smaller. This can be caused by flattening sample surface, which leads to more similar results obtained with different aperture. Since surface irregularities influence measured results, more even surface will lead to closer results, independent of aperture size. After applying third layer of UV varnish, this difference is higher. With applying every additional layer of UV varnish, colour difference between measurements with same geometry, but different aperture size, is higher. This change is almost linear, and is a little bit higher in case of de:8 measurements.

Comparing differences for d/8 measurement geometry between same measurement mode and different aperture size (3 mm and 8 mm), with differences between same aperture size but different mode (SCI and SCE), it can be concluded that aperture size has greater influence on measured results, than measurement mode. This can be explained by part of surface sample taken into observation and measurement, since surface is glossy and transparent. Influence of applied UV varnish on measurement is different, if different part of surface sample is observed, due to different transmission and reflection of light.



» **Figure 5:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8° spectrophotometer with measurement aperture 3mm and measurement aperture 8mm, for SCI and SCE measurements*

In order to express the difference in obtained measurements for each sample, but using different measuring geometries and aperture sizes, with one number, mean colour difference from the mean (MCDM) calculating method was used. This means that the CIEDE2000 between each measurement and the average Lab coordinates of the data set (data sets are Lab measurements obtained with different measuring geometries and aperture sizes for the unprinted sample and each layer of UV varnish) was calculated. The calculated average of each set of CIEDE2000 are the MCDM values presented in Table 2 (Nadal, Cameron Miller & Fairman, 2011). It can be noticed that with every additional layer of UV varnish, MCDM between measurement geometries is larger. This confirms influence of number of layers of UV varnish on difference between obtained values for different measuring geometries.

Table 2

Mean colour difference of the mean between measurement geometries for sample before and after applying each layer of UV varnish

	MCDM between measurement geometries
PVC plastic	0,33
1 UV varnish layer	1,06
2 UV varnish layers	1,67
3 UV varnish layers	2,08
4 UV varnish layers	2,41
5 UV varnish layers	2,62
6 UV varnish layers	2,71
7 UV varnish layers	2,65
8 UV varnish layers	2,96
9 UV varnish layers	3,22
10 UV varnish layers	3,30
11 UV varnish layers	3,67
12 UV varnish layers	3,67

Conclusions

From presented results it can be concluded that measuring geometry has great influence on measurement results of samples covered with UV varnish. Also, it can be concluded that with increase of numbers of UV varnish layers, difference between measurements also increases. Difference is largest between di:8/8mm and 45/0 measurements. Differences between d/8 and 45/0 geometries were generally larger when measurement aperture for d/8 geometry was larger. With increase of numbers of varnish layers, difference between measurements was also increasing, especially after application the first few layers of UV varnish, where difference between them is drastically changing. Differences in case of SCE geometry have the same trend as differences for SCI geometry, but they are a little bit smaller.

Differences between different modes, SCI and SCE, and also different measurement aperture size were also compared. In case of different mode, despite measurement aperture size, differences after applying UV varnish were fairly uniform, and not so significant. In case of measurement aperture size 3 mm, differences between SCI and SCE modes were in range from 1.29 to 1.74 for different number of applied layers, and in case of measurement aperture size 8 mm, differences were in range from 1.45 to 1.83. It can be noticed that difference between modes is not so pronounced, and this is probably due to imperfection of specular port.

In case of same mode, but different measurement aperture size, differences were linearly increasing with increased number of UV varnish layers. Differences for both modes were almost same. They are slightly lower in case of SCI mode. At first two layers of UV varnish, difference between measurements is lower than before applying UV varnish. This could be explained by flatter sample surface after applying UV varnish. This cause more similar results obtained with different aperture size. Since irregularities of surface influence results of measurement, more even surface will generate more uniform results, independent of aperture size, since influence of varnish gloss is still not so significant. With increasing number of UV varnish layers, difference is also increasing and becoming more significant. This is probably due to part of surface sample that is measured, since surface is glossy and transparent. Influence of UV varnish is different, if different part of surface sample is measured, due to different transmission and reflection of light. Considering all this, it can be concluded that aperture size has great influence on measured results, in case of extreme application of UV varnish.

Comparing obtained colour differences for different modes and different aperture sizes, in case of diffuse geometry, for PVC plastic UV varnished samples, with different amount of applied varnish, it can be concluded that aperture size has greater influence on measured results, than mode used.

Further research should be focused on examination of samples first printed with process colours, before applying UV varnish, to see how colour affects measurement results with different measurement geometries.

Acknowledgements

The authors declare that the presented investigation is not in any conflict of interest. The research is financially supported by the Ministry of Scientific and Technological Development, Higher Education and Information Society of the Republic of Srpska, project No.19.030/961-9-2/21 “Digital approach to the production of environmentally friendly packaging”.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Berns, R. S. (2019) *Billmeyer and Saltzman's principles of colour technology (Fourth Edition)*. Hoboken, Wiley.

Dalal, E. N. & Natale–Hoffman, K. M. (1999) The effect of gloss on colour. *Colour: Research and applications.* 24 (5), 369-376. Available from: doi: 10.1002/(SICI)1520-6378(199910)24:5<369::AID-COL8>3.0.CO;2-A

Datacolour (n.d.) *Gloss compensation: A Technical report on gloss and datacolour's gloss compensation.* Available from: https://repo.chromachecker.com/pdf/display/L7rYGO/EN/manual_colour_inspector_report_options [Accessed 6th September 2022]

Format Media Ltd. (2010) *DX4 Printhead - 1000002201- for Epson, Roland, Mimaki and Mutoh.* Available from: https://www.largeformatreview.com/hardware/wide-format-print/dx4-printhead-1000002201-for-roland-mimaki-and-mutoh-1000002201 [Accessed 16th September 2022]

Galić, E., Ljevak, I. & Zjakić, I. (2015) The Influence of UV varnish on colourimetric properties of spot colours. *Procedia Engineering,* 100, 1532-1538. Available from: doi: 10.1016/j.proeng.2015.01.525

International Organization for Standardization. (2009) ISO 3664:2009. *Graphic technology and photography - Viewing conditions.* Geneva, International Organization for Standardization.

Kandi, S. G. (2011) The Effect of spectrophotometer geometry on the measured colours for textile samples with different textures. *Journal of Engineered Fibers and Fabrics.* 6 (4), 70-78. Available from: doi: 10.1177/155892501100600410

Knowles Middleton, W. E. (1953) Comparison of Colourimetric Results from a Normal-Diffuse Spectrophotometer with Those from a 45-Degree-Normal Colourimeter for Semiglossy Specimens. *Journal of the Optical Society of America.* 43 (12), 1141-1143. Available from: doi: 10.1364/JOSA.43.001141

Luo, M. & Cui, G. (2009) Colour appearance and visual measurements for colour samples with gloss effect. *Chinese Optics Letters,* 7 (9), 869-872. Available from: doi: 10.3788/col20090709.0869

Luo, M. R., Cui, G. & Rigg, B. (2001) The development of the CIE 2000 colour-difference formula: CIEDE2000. *Colour Research & Application*. 26, 340-350. Available from: doi: 10.1002/col.1049

Majnarić, I., Bolanča Mirković, I. & Golubović, K. (2012) Influence of UV curing varnish coating on surface properties of paper. *Tehnički Vjesnik.* 19 (1), 51-56.

Milić, N., Novaković, D. & Kašiković, N. (2011) Measurement uncertainty in colour characterization of printed textile materials. *Journal of Graphic Engineering and Design.* 2 (2), 16-25.

Miloš, S., Vujčić, Đ. & Majnarić, I. (2021) Use and analysis of UV varnish printed braille information on commercial packaging products. *Journal of Graphic Engineering and Design.* 12 (4), 5-15. Available from: doi: 10.24867/JGED-2021-4-005

Nadal, M. E., Cameron Miller, C. & Fairman, H. S. (2011) Statistical methods for analyzing colour difference distributions. *Colour Research & Application.* 36 (3), 160–168. Available from: doi: 10.1002/col.20622

Randall, D. P. (1998) Instruments for the measurement of colour. *Textile chemist and colourist.* 30, 20-26.

Roland (2019) *ECO-UV, EUV-GL Ver. 2 - Safety Data Sheet.* Available from: https://www.rolanddg.kr/-/media/roland-apac/dgk/files/support/sds/euv2/euv2_gl_20190524.pdf?la=ko&hash=B-32C66BE4710D421B5A77C-848C488A74CF22A566 [Accessed 16th September 2022]

Vujčić, Đ., Kašiković, N., Stančić, M., Majnarić, I. & Novaković, D. (2021) UV ink-jet printed braille: a review on the state of the art. *Pigment & Resin Technology.* 50 (2), 93-103. Available from: doi: 10.1108/PRT-03-2020-0022

Yuan, K., Yan, H. & Jin, S. (2013) The design of colour spectrophotometer based on diffuse illumination and compatible SCE/SCI geometric condition. In: Tam, H.-Y., Xu, K., Xiao, H., Zhu, J. (eds.) *Proceedings of the SPIE 9046, 2013 International Conference on Optical Instruments and Technology: Optoelectronic Measurement Technology and Systems, OIT2013, 17-19 November 2013, Beijing, China.* SPIE. pp. 90460V-1 - 90460V-8. Available from: doi: 10.1117/12.2036508

Original scientific paper http://doi.org/10.24867/JGED-2023-4-033

The effect of carbonyl components of printing substrates on the durability of UV thermochromic prints

ABSTRACT

Special effects on a printed product can increase consumer's interest in a product and therefore lead to higher revenues in consumer industries. For that purpose, graphic industry introduced various technologies and materials that would have such an effect and enhance consumer-goods interaction. One of those solutions is thermochromic printing. Although bringing added value, thermochromic inks have some challenges in application due to their higher sensitivity, especially when exposed to UV light. Therefore, the goal of this work is to determine whether amount of the UV radiation during curing of UV thermochromic prints, as well as exposure after printing would degrade the thermochromic print on various substrates. UV thermochromic prints were made on three different paper printing substrates using the screen printing method and dried in a laboratory controlled unit. Synthetic paper, recycled paper containing 100 % recycled cellulose fibers and bulky voluminous paper were used as printing substrates. During the UV curing of the ink, no photooxidation of the prints occurred. Additional exposure of the prints to UV radiation (after the ink has hardened) leads to their photooxidative degradation, i.e., a change in the initial color. The obtained colour difference (ΔE) is increasing with the increase of the irradiation amount. The highest colour difference is on the synthetic paper while prints on two other substrates are more resistant to UV light. A print on synthetic paper photooxidizes the fastest due to the presence of most carbonyl groups in it. Generated free radicals promote the instability of prints on synthetic paper. Research has proven that when using synthetic paper or substrates with similar characteristics, care should be taken to accurately determine the amount of UV energy required for curing in order to prevent photodegradation of the ink. The results also show that to explain any degradation of prints, the chemical components of the paper needs to be taken into account, which is rarely done.

Mirela Rožić [1]
Tomislav Cigula [1]
Snežana Miljanić [2]

[1] *University of Zagreb, Faculty of Graphic Arts, Zagreb, Croatia*
[2] *University of Zagreb, Faculty of Science, Department of Chemistry, Zagreb, Croatia*

Corresponding author:
Mirela Rožić
e-mail: mirela.rozic@grf.unizg.hr

First received: 5.3.2023.
Revised: 29.4.2023.
Accepted: 5.5.2023.

KEY WORDS
Photooxidation, screen printing, thermooxidation, thermochromic ink

Introduction

Printing inks are colored complex mixtures, liquids or pastes consisting mainly of colorants (pigments or dyes), binders (resins), solvents (organic or aqueous-based) and additives (chelates, antioxidants, surfactants, biocides, etc.). Their composition and physical properties differ mainly with respect to the printing process for which they are intended. When applied to a substrate, the printing inks must change to a solid state. The inks must dry as quickly as possible and can be dried physically (evaporation) and chemically (oxidation, radiation-induced curing) or by a combination of both (White & LeBlanc 1999; Leach & Pierce, 2007).

Radiation-induced curing includes ultraviolet radiation, infrared radiation, electron beams, microwaves, and radio frequency. Ultraviolet (UV) inks are hardened by UV radiation. UV curing (ultraviolet curing) is a process that uses ultraviolet light to initiate a photochemical reaction that creates a cross-linked polymer structure. It can be used in flexographic, offset, screen printing and pad printing processes. UV curing is used in the finishing of instruments (guitars, violins, etc.), the production of billiard cues and other wooden objects. UV printing is possible on different substrates such as plastic, paper, canvas, glass, metal, films and many other materials. The main advantage of curing with UV light is the speed of production, i.e., there is no need for drying time between printing and finishing. Speeding up drying can reduce defects and errors by reducing the amount of time the ink spends wet. This can increase the quality of the finished product (Leach & Pierce, 2007; Robert, 2015; MacLaren & White, 2003).

Thermochromic printing inks change color under the influence of heat (Civan et al., 2020). Instead of classic pigments, they contain microencapsulated leuco dye-developer-solvent systems. They can also contain a mixture of classic pigment and microcapsules. The thermochromic effect is caused by the formation of a leuco-dye developer complex inside the microcapsules. The microcapsules typically have an average particle size of a few micrometers (Phillips, 2000; Ma et al., 2020; Panák et al., 2017).

Many thermochromics dyes are of the spirolactone type. A common example is crystal violet lactone (CVL). The thermochromic mixture is about 75–95 mol % solvent, the solvent melting point largely controls that of the mixture. Long-chain alkyl alcohols are most often used as solvents. Microcapsules are dispersed in a vehicle. The most widely used system for microencapsulation of thermochromic inks involves urea, melamine, melamine-formaldehyde, gelatine-gum arabic and epoxy resins (MacLaren & White, 2003; Panák et al., 2017).

The thermochromic inks communicate with the customer by changing appearance as the ambient temperature changes, providing additional information. On the other hand, their composition with microcapsules makes them sensitive in application and use. The microencapsulated thermochromic pigments usually have medium particle size of a few micrometres, which is about ten times larger than the particle size of conventional pigment particles.

In this paper, prints of thermochromic ink that hardens with UV radiation on three different paper substrates were analyzed. The aim of the work was to determine whether paper components affect the UV stability of ink prints.

Materials and Methods

Printing substrates, printing ink and printing trials

For this study, three different paper substrates were used for printing with UV curable thermochromic screen printing ink: synthetic paper (Yupo, 73 g/m²) extruded from polypropylene pellets, recycled paper (Mondi, 80 g/m²) containing 100 % recycled cellulose fibres, bulky voluminous paper (Munken Print White, 80 g/m²), which contains woodfree pulp and more than 10 % groundwood pulp.

A leuco dye based, UV curable screen printing ink (Chromatic Technologies, Inc.) with an activation temperature of 31°C (according to the manufacturer) was used to print the paper samples. Below the activation temperature, the thermochromic UV curable screen printing ink was purple in colour; above the activation temperature, the printing ink was pink. The ink was printed using a semi- automated (squeegee motion) screen printing device (Holzschuher K.G., Wuppertal, Germany) with a 60/64 screen printing mesh. The printed samples were dried under UV irradiation (30 W/cm) using the Technigraf Aktiprint L 10-1 device. All samples were printed in solid colour. The samples were denominated as: B – print on bulky paper, R – print on recycled paper, S – print on synthetic paper.

For the determination of UV light degradation, the dried samples were further exposed to UV radiation using the Technigraf Aktiprint L 10-1 device for defined energy in of 1–5 J/cm². The energy was determined using the Technigraf UV-Integrator which measures in the wavelengths between 320–420 nm.

Kappa number of bulky paper

The lignin content in bulky paper was determined by the method Kappa pulp number, Test method TAPPI/ANSI T 236 om-22 TAPPI/ANSI T 236 om-22. The kappa number is a key test method for determining the lignin content remaining in a sample. The kappa number is based on the reaction of a strong oxidizing chemical, potassium permanganate, with lignin, as well as small amounts of other organic impurities remaining in the pulp. The percentage of lignin in a sample whose kappa number is determined by the procedure in the specified standard test method is approximately determined using the following equation:

Lignin level (%) = Kappa number × 0.13

Infrared (IR) spectra

To analyze the printing substrate composition, infrared (IR) spectra of the papers were recorded using

the attenuated total reflectance (ATR) technique. A Bruker Equinox 55 interferometer, equipped with a Pike Technologies MIRacle ATR holder with a reflection crystal made of diamond and ZnSe, was used to acquire the ATR spectra. The spectra were measured in the 4000-600 cm^{-1} spectral range at a resolution of 4 cm^{-1}, averaged over 32 scans. The raw ATR spectra were corrected using the extended ATR correction algorithm.

Scanning electron microscopy (SEM) of prints

JSM-7000F, thermal field emission scanning electron microscope (FE SEM) manufactured by Jeol Ltd., was used to assess print's surface. FE SEM was coupled with EDS/INCA 350 (energy dispersive X-ray analyzer) manufactured by Oxford Instruments Ltd. The prints inspected by FE SEM were coated with a conductive layer.

Colour measurement

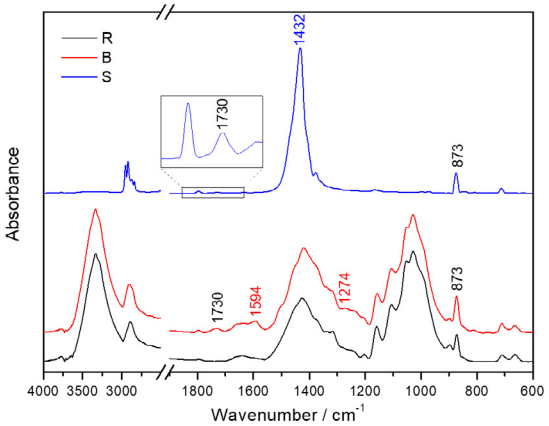
In order to determine the hysteresis curves, the prints were heated and then cooled on a thermoregulating metal plate in the temperature interval in which they change color: from 22.5 °C to 30 °C. Measurements of colourimetric CIE Lab values L*, a*, b* on printed paper substrates were performed using SpectroDens (manufacturer Techkon).

Colorimetric values are the result of averaging 20 measurements for each parameter. Color differences between non-irradiated and UV-irradiated samples and samples at different temperatures were calculated using the ΔELab equation (Mokrzycki & Tatol, 2011).

Results and discussion

The IR analysis of the printing substrate composition

The qualitative composition of the papers was analyzed by means of the IR spectroscopy (Figure 1). The ATR spectra of recycled and bulky papers corresponded mostly to cellulose, indicated by the strong broad bands of the O–H stretching (3330 cm^{-1}), COH and HCC deformation (1500–1300 cm^{-1}), C–C and C–O stretching (1160–950 cm^{-1}) as well as COC and CCO deformation (899 cm^{-1}) of the glucopyranose ring (Proniewicz et al., 2001). Beside the cellulose bands, the phenyl ring vibrational bands (1594 and 1274 cm^{-1}) were observed in the ATR spectrum of bulky paper, pointing to presence of lignin in its structure (Derkacheva & Sukhov, 2008). Unlike the cellulose-based papers, the intense band (1432 cm^{-1}) observed in the ATR spectrum of synthetic paper, was assigned to the methyl and methylene deformations, confirming that the synthetic printing substrate was mainly composed of polypropylene. In addition, in the spectra of all the studied papers, a moderate band at 873 cm^{-1} was observed and associated with calcium carbonate. Interestingly, a weak band (1730 cm^{-1}) attributed to the carbonyl stretching was observed in the ATR spectra of bulky and synthetic paper, but not assigned to any of the main constituents of the printing substrates.



» **Figure 1:** *ATR spectra of the paper substrates; S-synthetic, B-bulky, R-recycled paper*

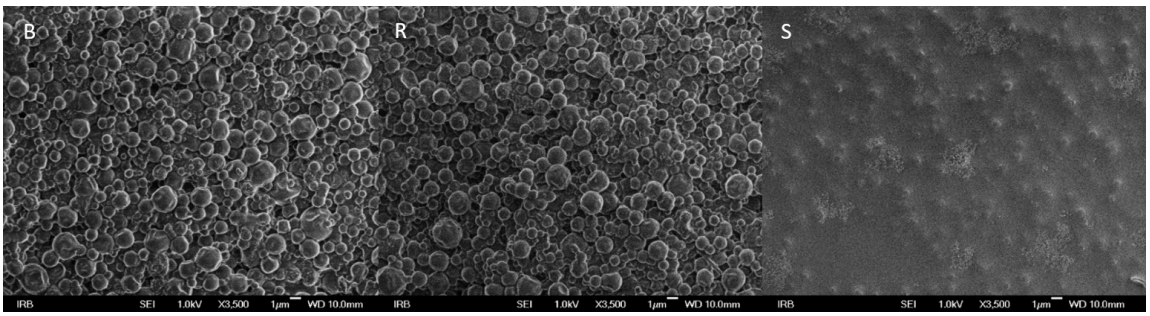
Scanning electron microscopy (SEM) of prints

The binder in the tested ink is polyurethane acrylate containing chromophoric C=O and N–H groups (Vukoje et al., 2018). It is evident from the SEM images (Figure 2) that the binder was almost completely absorbed into the structure of recycled and bulky paper, and almost not at all into the structure of synthetic paper. SEM analysis shows that the microcapsules and the binder did not degrade (photooxidized) under the influence of UV light used to polymerize the prints after printing.

After coating the ink on the paper, the air inside the system should leave the ink film while the viscosity is still low enough. The atomized air in the system that remains in the system is called microfoam. Such microfoams are visible in the SEM image of the print on the synthetic paper.

Hysteresis

The color change from purple to pink on all prints (Figure 3) occurs between temperatures of 22.5 °C and 28 °C which is below the temperature specified by the manufacturer (31 °C). By heating the print, the solvent inside the microcapsules dissolves. The blue-colored complexes between the dye and the developer inside the microcapsules are separated under the influence of the solvent, the blue color changes to colorless. Only the pink color of the classic pigment remains. At temperatures below the melting point of the solvent, the classic pink pigment and



» **Figure 2:** *SEM micrograph of UV print on bulky (B), recycled (R) and synthetic (S) paper under magnifications of 3500x*

blue colored microcapsules give a purple color. Based on the colorimetric values of the prints from Figure 3, it is evident that all the prints are stable to the diffusion of the components from the microcapsules. The heating curves are equal to the cooling curves. The photos show prints taken after a warm-up cycle.

If the initial -b* value is taken as a measure of the concentration of blue-colored microcapsules, and the +a* value is taken as a measure of the concentration of pink pigment, then based on a* and b* values it can be concluded from Figure 3 that the highest concentration of microcapsules is on recycled paper (the smallest b* value), and the pink pigments together with binder is on synthetic paper (the largest a* value). The reason for the highest concentration of pigments and binder on the surface of the synthetic paper is the weak absorption of the binder into the structure of the synthetic paper.

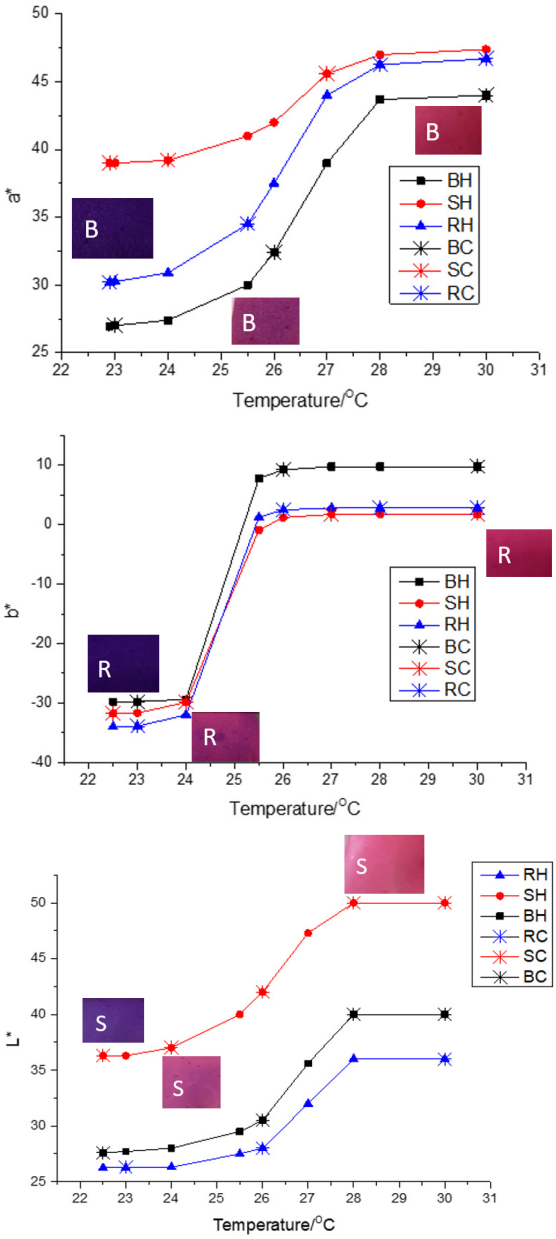
According to the literature, microcapsules are polar. They contain hydroxyl and amino groups. In the tested UV ink, they are contained in a polyurethane acrylate binder that contains C=O and NH groups. Hydroxyl and amino groups of microcapsules enter hydrogen interactions with NH groups of binders and dipole-dipole interactions with carbonyl groups of binders. Therefore, the same concentration of microcapsules in the binder can be assumed before application to the paper. Microcapsules are adsorbed on paper surfaces as part of the binder. If the binder has a higher affinity to the paper substrate, more microcapsules will be adsorbed.

According to the obtained colorimetric values, the most microcapsules were adsorbed on the surface of recycled paper, and somewhat less on the surface of bulky paper. Bulky paper contains 1.17 % lignin, which reduces the hydrophilicity of cellulose and fillers. However, this proportion is quite small, so it causes only a slight decrease in the sorption of binders and microcapsules on its surface. The SEM images show that the entire surface of the recycled and bulky paper has been used as far as microcapsules are concerned, while the synthetic paper has not. Synthetic paper contains 44.5 wt% of calcium carbonate (Rožić et al., 2020). Ion-dipole interactions are stronger compared to hydrogens and dipole-dipole. Despite the stronger attractive forces, the sorption of microcapsules on synthetic paper should be significantly lower considering its composition. Microcapsules are adsorbed in places rich in calcium carbonate, and the binder is adsorbed in these areas by ion-dipole interactions. Microcapsules are densely packed when adsorbed on areas rich in calcium carbonate. So, they are not in one layer but in several layers. Therefore, the b* values of prints on synthetic paper are similar to prints on recycled paper containing 100% active polar and ionic components.

At 22.5 °C, the lightest print is on synthetic paper (the highest L* value) due to the highest concentration of pink pigment on its surface. The darkest print is on recycled paper due to the highest concentration of blue colored microcapsules.

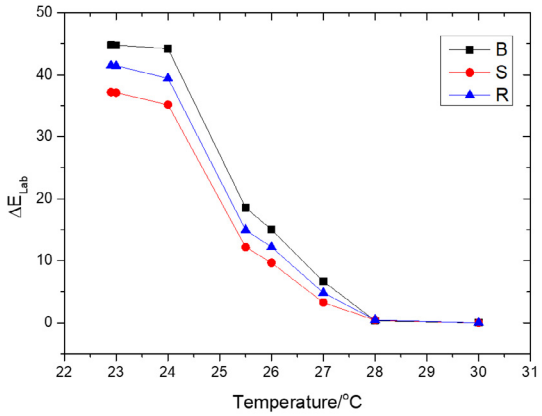
At a temperature of 25.5 °C, b* values take on positive values. b* values move into the yellow area. Print on bulky paper is the yellowest (b*=9.78), followed by recycled (b*=2.82) and synthetic paper (b*=1.75). The b* value of the bulky paper (Rožić et al., 2020) itself cannot cause such a large b* value of the print on the bulky paper at the end of heating. It is possible that some component from the ink was adsorbed on the surface of the bulky paper in a larger amount than on the other substrates, which causes a positive b* value. Some possible additives in UV ink include adhesion promotors, pigment dispersing agents, and gloss promotors.

Based on the chemical structure, it can be assumed that the increased b* values are caused by gloss enhancers such as hydroxypropyl methylcellulose and lecithin (Warzeska et al., 2002). Hydroxypropyl methylcellulose and lecithin are weakly polar molecules that may have a greater affinity for lignin in bulky paper. The dispersion, polar and dipole components of hydroxypropyl methylcellulose and lecithin are similar to those of lignin because their chemical structures are also similar.



» **Figure 3:** *L*, a*, b* values of prints depending on heating and cooling temperatures; H=heating, C=cooling-Photographs of prints taken at temperatures of 22 °C, 24.5 °C and 28 °C; S-synthetic, B-bulky, R-recycled paper*

Figure 4 shows the color contrasts of the prints at different temperatures with respect to the colorimetric values of the prints at 30 °C as reference values. Color contrasts are greatest up to a temperature of 24 °C, which is to be expected, because prints are the most purple at those temperatures. They are the greatest for print on bulky paper. The smallest color contrast on synthetic paper is a consequence of its insufficient porosity. This is why it already has a high concentration of pink pigment on the surface and approximately the same concentration of blue-colored microcapsules as other papers. As far as savings or green printing is concerned, it is favorable. However, because of this, it gives slightly less color contrast compared to other prints, but the color contrast is clearly visible in any case. Color contrasts decrease in the temperature range from 22 °C to 28 °C.



» **Figure 4:** *Color contrasts of thermochromic offset prints with respect to the colorimetric values of the prints at 30 °C; S-synthetic, B-bulky, R-recycled paper*

Photooxidation of prints

Although the prints proved to be stable to UV radiation during printing, the research involved additional UV light (after drying) since these inks are sensitive to UV light. The results of the colour measurement of UV exposed prints is presented in Table 1.

Table 1

Colour difference between initial and samples exposed to UV energy

Sample	Irradiation (J/cm²)	ΔE lab
B	0	0
	1	2.24
	3	4.28
	5	5.39
R	0	0
	1	2.03
	3	3.87
	5	4.78
S	0	0
	1	5.89
	3	8.88
	5	9.24

The highest colour difference can be seen on synthetic paper where even lowest additional irradiation energy causes significant colour change. Color changes visible to the eye are greater or equal to 5 (ΔE). On the other substrates it is visible that even the highest additional irradiation did not cause colour change obtained on synthetic paper after 1 J/cm².

The results of the research by Rožić & Vukoje (2018) show the heterogeneous nature of the photooxidative degradation of thermochromic UV prints.

The UV ink microcapsules and the polar polymer binder can form strong hydrogen and dipole-dipole bonds between the NH groups of the binder and the –OH and –NH (-NH_2) groups of the microcapsules. The number of available chromophoric groups of binders and microcapsules is thus reduced. The areas where the microcapsules and the binder are connected by hydrogen bonds are stable. Only the binder on the surface of the microcapsules and possibly the pigment are fotodegraded. However, since polyurethane acrylate contains much more polar groups compared to microcapsule materials, the number of bonds between microcapsules and the binder is small. This means that the binder on the surface of the microcapsules still has a high concentration of chromophore groups. Since the polypropylene areas of synthetic paper is less absorbent than the others used in this study, the number of surface chromophore groups is the highest on the print on its surface but not too much compared to the surfaces of prints on bulky and recycled paper. Prints on bulky and recycled paper have a slightly lower surface number of carbonyl and amino groups. Bulky paper has the lowest chromophore groups concentration. Therefore, a print on bulky paper should degrade the least, and it degrades faster than a print on recycled paper. According to the results of the IR analysis, bulky and synthetic papers contain carbonyl groups that cannot be linked to their other ingredients.

Carbonyl compounds can be added to polymers as additives that accelerate fotooxidation degradation. Such an initiator is, for example, benzophenone (Geuskens & Kabamba, 1987). Besides ketones, quinines and peroxides are also initiators of photodegradation reactions of organic compounds. All of them absorb light up to about 380 nm, which causes their excitation or cleavage into radicals (Chew, Gan & Scott, 1977). The influence of low-molecular organic compounds such as benzophenone, anthraquinone and benzoyl peroxide on the photodegradation of polystyrene was investigated in the work of Yousif & Haddad (2013). The results show that these additives accelerate and increase the photooxidation of polystyrene. The presence of carbonyl groups as defects in the structure of poly(p-phenylenevinylene) (PPV) is widely known.

In the paper (Papadimitrakopoulos et al., 1994) it was proved that carbonyl defects can be introduced thermally and photochemically. Although PPV is quite thermally stable, its defects containing hydroxyl groups are very sensitive to reaction with traces of oxygen at elevated temperatures resulting in the formation of ketone-based carbonyl impurities. Photooxidation of PPV involves cleavage of the vinyl double bond and formation of terminal aldehyde groups.

In the work (Kunwong, Sumanochitraporn & Kaewpirom, 2011), 2,2-dimethoxy-2-phenyl acetophenone was used as a photoinitiator in the polymerization reaction of a UV-curing coating based on urethane acrylate oligomer. Accordingly, carbonyl compounds are also used as photoinitiators in ink UV curing.

The reason for the higher rate of photooxidation of prints on synthetic paper should be sought in the paper structure itself. As mentioned, carbonyl compounds are added to polymers to accelerate photooxidation. According to IR analysis, certain carbonyl compounds are also found in bulky paper, so this is the reason for its faster decomposition even though it contains the least binders.

Conclusions

This research was conducted to determine the influence of the substrate on the UV stability of a thermochromic UV curing ink applied in the screen printing process. In addition, the goal is to determine the effect of higher exposure to UV light than is used to cure the ink film.

The research has proved that used substrate has significant influence on the thermochromic effect, but on the resistance to additional UV light exposure as well. Furthermore, when using synthetic paper, or substrate with similar characteristics one should take proper care to precisely determine UV energy amount needed for curing in order to prevent ink's photodegradation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Chew, C. H., Gan, L. M. & Scott, G. (1977) Mechanism of the photo-oxidation of polyethylene. *European Polymer Journal.* 13 (5), 361-364. Available from: 10.1016/0014-3057(77)90095-7

Civan, L., Kurama, S., Ayas, E. & Mutlu, Y. Ç. (2020) Control of temperature changes in daily life with thermochromic green pigments. *Materials Letters.* 272, 127846. Available from: doi: 10.1016/j.matlet.2020.127846

Derkacheva, O. & Sukhov, D. (2008) Investigation of Lignins by FTIR Spectroscopy, *Macromolecular Symposia.* 265 (1), 61-68. Available from: doi: 10.1002/masy.200850507

Geuskens, G. & Kabamba, M. S. (1987) Photo-oxidation of polymers: Part X—The photo-oxidation of an ethylene-propylene copolymer initiated by benzophenone. *Polymer Degradation*

and Stability. 19 (4), 315-322. Available from: doi: 10.1016/0141-3910(87)90033-4

Kunwong, D., Sumanochitraporn, N. & Kaewpirom, S. (2011) Curing behavior of a UV-curable coating based on urethane acrylate oligomer: The influence of reactive monomers. *Songklanakarin Journal of Science and Technology.* 33 (2), 201-207.

Leach, R. H. & Pierce, J. (2007) *The Printing Ink Manual, 5th ed.* Dodrecht, Springer. Available from: doi: 10.1007/978-1-4020-6187-5

Ma, X., Zhao, S., Wang, L. & Zhou, H. J. (2020) Research on the behaviors of extending thermochromic colors for a new thermochromic microcapsule. *The Journal of The Textile Institute.* 111, 1097–1105. Available from: doi: 10.1080/00405000.2019.1684224

MacLaren, D. C. & White, M. A. (2003) Dye–developer interactions in the crystal violet lactone–lauryl gallate binary system: Implications for thermochromism. *Journal of Materials Chemistry.* 13 (7), 1695–1700. Available from: doi: 10.1039/B302249H

Mokrzycki, W. & Tatol, M. (2011) Color difference Delta E- A survey. *Machine Graphics and Vision.* 20 (4), 383–411.

Panák, O., Držková, M., Kaplanová, M., Novak, U. & Klanjšek Gunde, M. (2017) The relation between colour and structural changes in thermochromic systems comprising crystal violet lactone, bisphenol A, and tetradecanol. *Dyes and Pigments.* 136, 382–389. Available from: doi: 10.1016/j.dyepig.2016.08.050

Papadimitrakopoulos, F., Yan, M., Rothberg, L. J., Katz, H. E., Chandross, E. A. & Galvin, M. E. (1994) Thermal and Photochemical Origin of Carbonyl Group Defects in Poly-(P-Phenylenevinylene). *Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals.* 256 (1), 663-669. Available from: doi: 10.1080/10587259408039307

Phillips, G. K. (2000) Combining thermochromics and conventional inks to deter document fraud. In: van Renesse, R. L., Vliegenthart, W. A. (eds.). *Proceedings of the SPIE 3973, Optical Security and Counterfeit Deterrence Techniques III, 27–28 January 2000, San Jose, California.* SPIE. pp. 99–104. Available from: doi: 10.1117/12.382179

Proniewicz, L. M., Paluszkiewicz, C., Wesełucha-Birczyńska, A., Majcherczyk, H., Barański, A. & Konieczna, A. (2001) FT-IR and FT-Raman study of hydrothermally degradated cellulose. *Journal of Molecular Structure.* 596 (1-3), 163-169. Available from: doi: 10.1016/S0022-2860(01)00706-2

Robert, T. (2015) "Green ink in all colors"- Printing ink from renewable resources. *Progress in Organic Coatings.* 78, 287–292. Available from: doi: 10.1016/j.porgcoat.2014.08.007

Rožić, M, Šegota, N, Vukoje, M, Kulčar, R. & Šegota, S. (2020) Description of thermochromic offset prints morphologies depending on printing substrate. *Applied Sciences.* 10 (22), 8095. Available from: doi: 10.3390/app10228095

Rožić, M. & Vukoje, M. (2018) Photo-oxidation stability of microcapsules in thermochromic prints. *Acta Graphica.* 28 (3), 109-116. Available from: doi: 10.25027/agj2017.28.v28i3.138

Vukoje, M., Miljanić, S., Hrenović, J. & Rožić, M. (2018) Thermochromic ink- paper interactions and their role in biodegradation of UV curable prints. *Cellulose*. 25 (10), 6121-6138. Available from: doi: 10.1007/s10570-018-1970-5

Warzeska, S. T., Zonneveld, M., van Gorkum, R., Muizebelt, W. J., Bouwman, E. & Reedijk, J. (2002) The influence of bipyridine on the drying of alkyd paints: A model study. *Progress in Organic Coatings.* 44 (3), 243–248. Available from: doi: 10.1016/S0300-9440(02)00057-7

White, M. A. & LeBlanc, M. (1999) Thermochromismin Commercial Products. *Journal of Chemical Education.* 76 (9), 1201–1205. Available from: doi: 10.1021/ed076p1201

Yousif, E. & Haddad, R. (2013) Photodegradation and photostabilization of polymers, especially polystyrene: review. *SpringerPlus*. 2. Available from: doi: 10.1186/2193-1801-2-398